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Principles of or

THE PRINCIPLES *of* ORGANIC CHEMISTRY

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PREFACE TO THE THIRD EDITION

In this revision there have been introduced into the book those advances in organic chemistry which, in the opinion of the author, should find a place in a textbook designed primarily to meet the requirements of students beginning the study of the science. The pedagogical aspect of the problem was paramount, and the opportunity was taken to improve the treatment of the subject from this point of view.

Some of the discussions have been simplified and abbreviated, and the material has been separated into a larger number of sections. Italics have been used to emphasize generalizations, and topics of a more special nature are printed in small type. It is believed that these changes in form will facilitate the use of the book by the beginner. Although much new material has been added, the changes and few omissions made have resulted in a book with fewer pages than the second edition.

A number of new industrial processes and compounds are described briefly as illustrations of the application of the principles emphasized. The chapter on proteins has been revised, a new chapter on alicyclic compounds has been introduced, and the use of thermochemical data in simple types of reactions has been extended.

The physical constants given are those recorded in "International Critical Tables." Special attention has been paid to nomenclature. The problems are new and include other types than those of the earlier editions.

The author wishes to express his great indebtedness for valuable suggestions to Professor Austin M. Patterson, who read the galley proofs of the book with unusual care.

JAMES F. NORRIS.

CAMBRIDGE, MASS.,
May, 1931.

PREFACE TO THE FIRST EDITION

THIS book is the outcome of a number of years' experience in teaching the elements of organic chemistry to classes of beginners in the subject. In it an attempt has been made to emphasize the fundamental principles of the science, and to describe in some detail the organic compounds of practical importance. The substances considered have been selected from this point of view. As a consequence, many compounds of interest to the more advanced student have been omitted; the space gained in this way has been devoted to a fuller consideration of the more important typical reactions of organic compounds, and the applications of the science have been treated at greater length than is customary in elementary textbooks.

The order in which the several classes of compounds are discussed differs from that usually followed, and is the result of the emphasis placed on the effect of the nature of organic radicals on the properties of compounds containing them. To bring out clearly this effect, the radicals are referred to hydrogen as a standard; those more base-forming than hydrogen are classed as positive, and those more acid-forming as negative. The selection of the terms positive and negative is, perhaps, unfortunate, on account of the fact that these words have been used in other connections with a different meaning from that employed here. But no more expressive terms appear to be available, and they have been often used in organic chemistry with the significance assigned to them in this book. Alcohols consist of a positive radical in combination with the hydroxyl group, and acids of a negative radical with this group. This view leads to a consideration of acids after alcohols have been described. The relationship existing between the two classes of compounds and their analogies to inorganic bases and acids can be clearly emphasized from this point of view. Next are considered ethers, anhydrides, and esters, compounds which contain, respectively, two positive radicals, two negative radicals, and one positive and one negative radical

linked to oxygen. The classing of these three types of compounds together makes it possible to bring out the relationship between the properties of compounds and the character of the radicals they contain. The consideration of alkyl and acyl halides, and of amines and amides, in a similar way facilitates markedly the study of the properties of these compounds.

On account of the increasing attention paid to organic chemistry as a basis for the study of foods, the carbohydrates, fats, and proteins have been treated more fully than is customary in elementary textbooks. Although the investigations of Fischer and his co-workers have placed the study of the proteins on a scientific basis, work has not advanced sufficiently far to warrant a strictly chemical classification of these compounds. The proteins are considered, therefore, according to the classification adopted by the American Society of Biological Chemists and the American Physiological Society. Some of the more important results of Fischer in the study of the hydrolysis of proteins and the syntheses of polypeptides have been given.

The methods used in the identification of organic substances have been described and illustrated by examples. The reactions of analytical significance of the various classes of compounds have been summarized in Chapter XVII. The identification of simple substances is becoming more and more a part of the laboratory practice in organic chemistry. The experience of the author has convinced him that this kind of work has great pedagogical value and can replace profitably a part of the synthetic work of the student. The book aims to furnish the elementary facts required for such work. In Chapter XVII the methods of deducing the structure of a compound from the results of the ultimate analysis of the compound and certain of its derivatives are illustrated by examples.

Problems are given at the end of most of the chapters. These are not merely "quiz" questions on the text; their solution involves, in most cases, a careful study of the principles discussed and their intelligent application. The solution of problems such as those given has been found to be of the greatest value to the student.

The author wishes to express his thanks to Prof. W. T. Hall, of the Massachusetts Institute of Technology and Prof. Alice F. Blood, of Simmons College, for valuable criticism and suggestions. He is especially grateful to his wife, who copied the entire manuscript of the book, assisted in proofreading, and helped in many ways that made the preparation of the book possible.

J. F. Norris.

Boston, Mass.,
March 1912.

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ORGANIC CHEMISTRY

CHAPTER I

SCOPE AND METHODS OF ORGANIC CHEMISTRY

1. About the middle of the seventeenth century the study of the substances which occur in nature had so far developed that chemists grouped them, in an endeavor to systematize their knowledge, according to what they called the "three kingdoms" of nature. Chemistry was thus divided into three branches: animal, vegetable, and mineral. It was only when it was discovered later that certain compounds are formed in the growth of both animals and plants, that the distinction between animal and vegetable chemistry disappeared, and all substances produced as the result of organized life-processes were designated by the term *organic*. It was believed that organic compounds were formed as the result of the so-called "vital force" in living things, and that they could not be produced by chemists. In 1828, however, Wöhler discovered that ammonium cyanate, a so-called inorganic compound, could be transformed into urea, a typical organic substance, which results from the changes that certain foods undergo in the body. As the study of organic compounds advanced, it was found that many of them could be prepared in the laboratory from the elements of which they are composed. The sharp distinction between inorganic and organic compounds based on the vital force, accordingly, disappeared. The term organic chemistry has survived, however. In this division of the science of chemistry, not only the substances formed as a result of life energy in plants and animals are studied, but also the compounds prepared from these substances, of which many thousands are known.

The element carbon is present in all these so-called organic compounds and, as a consequence, organic chemistry may be

defined as the chemistry of the carbon compounds. The student is already familiar with the chemistry of carbon in the elementary condition, of carbon monoxide and dioxide, and of the carbonates. As these substances are constituents of the mineral world they are considered as a part of inorganic chemistry. All other carbon compounds are classified, for convenience, under organic chemistry.

2. Although the compounds of carbon follow in their transformations the same fundamental laws as do the compounds of other elements, nevertheless, it is advisable to study them in detail after a knowledge of inorganic chemistry has been gained. A number of reasons have led to this setting off of the compounds of carbon for separate treatment. The chemical properties of these substances are different from those of the analogous compounds of other elements; for example, the chlorides of the metals react with silver nitrate in aqueous solution and are decomposed by concentrated sulphuric acid, whereas the chloride of carbon is comparatively inert and is not readily affected by these reagents. Again, when oxygen and hydrogen in the form of the hydroxyl group are in combination with carbon, as in alcohol, $C_2H_5.OH$, the substance is not affected by dilute acids or alkalies, whereas this group in combination with other elements imparts to the resulting compound acidic or basic properties. These differences between organic and inorganic compounds, and many others of a similar nature, are due to the fact that most inorganic compounds are broken down into ions when brought into solution, and act readily with other ionized substances, whereas in the case of organic compounds a small number only undergo such ionization. Organic chemistry involves to a large extent the study of reactions between molecules, whereas in inorganic chemistry ionic reactions are of prime importance.

Many compounds of carbon exist which are unlike any known compounds of other elements. This is due to the fact that the carbon atom has the power to unite with itself and form molecules of great complexity. Compounds have been studied which contain over 60 carbon atoms in the molecule. Where so many atoms are present there is, evidently, opportunity for a number of different arrangements of the atoms; for example, there are 86 compounds of the formula $C_{10}H_{12}O_3$. This is an added source

of complexity, and methods of study must be devised and used which are not necessary in inorganic chemistry where such complexity does not exist.

Importance and Applications of Organic Chemistry

3. The field covered by organic chemistry is a wide one. The changes which take place in our bodies involve the transformation of organic substances; the digestion and assimilation of food are chemical processes in which complex carbon compounds take part. As a consequence, a correct understanding of physiology requires a knowledge of physiological chemistry, which is a branch of organic chemistry. The investigation of the composition of foods and the study of methods for their analysis must be preceded by a study of the principles of organic chemistry upon which such investigation is based. The science of medicine makes use of many organic compounds on account of their effect on the body. An important branch of organic chemistry involves the preparation of new substances and a study of their action as drugs.

We come in contact with many organic compounds in our daily life on account of their useful or esthetic value, and such compounds assume an important place in commerce. In addition to foods may be mentioned condiments, paints, illuminating oils, dyes, etc. The study of such substances involves the determination of the properties of the individual compounds and the changes which they undergo under a variety of circumstances. These transformations give the chemist such a clear conception of the nature of the compounds that in many cases it has been found possible to synthesize (*i.e.*, build up) a substance which occurs in nature from other simple and readily obtainable substances. The synthesis of Turkey red, a highly prized dye found in madder root, is an interesting example. Some years ago thousands of acres of land were given up to the growing of madder, in order to produce this dye. The substance, which is a definite chemical compound, was extracted in pure condition and carefully studied. As a result, a method was devised to build up the dye from anthracene, a comparatively cheap substance, which is found in the tar formed when coal is

distilled in the preparation of coal gas. As the result of this application of organic chemistry the synthetic dye replaced that produced by nature, and large tracts of land were restored to other agricultural uses.

Many valuable substances which occur in nature have been produced in the laboratory in a similar way. But the chemist has not been content to build up only naturally occurring compounds. New substances having valuable properties have been prepared and, as a result, a great industry based on organic chemistry has been built up. Synthetic dyes, resins, lacquers, varnishes, and other valuable substances hold an important place in commerce.

Organic chemists have prepared a large variety of organic compounds that are used by physicians to combat disease. The preparation and use of such substances have become so important that the special name chemotherapy has been given to this field of science. Synthetic anesthetics, soporifics, etc., are widely used.

In addition to the applications of organic chemistry from the utilitarian point of view, the study of the compounds of carbon has resulted in the building up of a well-developed science, and has increased to a marked degree our knowledge of the transformations in matter.

Sources of Organic Compounds

4. Organic compounds are formed in nature in the growth of plants and animals. From this source we obtain starch, sugar, fats, the so-called vegetable acids, cellulose, proteins, alkaloids, etc. Many of these substances undergo decomposition as the result of certain natural processes, or can be broken down into simple compounds by methods used in the laboratory. Fermentation yields many important compounds; alcohol is formed by this process when a solution of sugar which contains yeast is allowed to stand for some time. Acetic acid, which gives the acid taste to vinegar, is formed as the result of the fermentation of the sugar in the fruit from which the vinegar is prepared.

A large number of compounds is produced by what is known as destructive distillation. This process consists in heating substances which cannot be converted into vapor without under-

going change, to such a temperature that decomposition takes place. As this temperature is often a high one, the substance is usually protected from the air in order to prevent complete combustion. A familiar example of destructive distillation is the manufacture of coal gas. Coal is a mixture of certain complicated compounds of carbon, hydrogen, nitrogen, and other elements. At a high temperature these compounds are decomposed, and if air is excluded a large number of substances is formed. Illuminating gas and coal tar, which is rich in organic compounds of the greatest interest and value, are among the products formed. The destructive distillation of wood and of bones also yields important substances. Petroleum contains a large number of compounds of carbon and hydrogen. The sources mentioned furnish substances from which many others can be prepared by the application of the methods used in organic chemistry.

Methods Used in the Study of Organic Compounds

5. The first step in the study of a substance is to obtain it in a pure condition. The tests which are usually applied in investigating the purity of an organic compound are based on the determination of certain physical properties. When a substance melts or boils without decomposition, the temperatures at which these changes take place under the same external conditions are definite and constant in the case of a pure substance. As determinations of melting points and boiling points are easily made, these properties are the ones usually studied in investigating the purity of most organic compounds.

Determination of Melting Points.—Melting points are determined by using an apparatus which consists of a round-bottomed flask of 100-c.c. capacity and a small test tube which fits loosely in the neck of the flask and extends to within about one-half inch of the bottom. The flask is supported on an iron stand by means of a clamp, and filled with concentrated sulphuric acid to about three-fourths of its capacity. Sulphuric acid is placed in the test tube also, care being taken to have the surface of the acid slightly below the level of that in the flask. The thermometer is held in place by means of a stopper, from which

a slit has been cut so that the graduations of the thermometer are visible. The substance to be melted is powdered and placed in a small glass tube which has an internal diameter of about one millimeter. The tube is attached to the thermometer by means of a rubber band cut from a piece of the tubing used for making gas connections in the laboratory.

What is called the melting point of a particular sample of any substance is the temperature at which the sample begins to melt and the temperature at which it completely liquefies. For example, these points were found to be 115° and 118°, respectively, in the case of an impure sample of benzoic acid. In this case the sample was said to have the melting point 115° to 118°.

When a substance is pure it melts at a definite temperature, *i.e.*, it completely liquefies at the temperature at which it first shows signs of melting. Such a substance is said to melt sharply. If a substance melts within 0.5° in the apparatus which has been described, it may be considered pure for most purposes.

The temperature read on the thermometer is usually taken as the melting point. If this is high, however, a correction is made to eliminate the error arising from the fact that a part of the mercury is not heated to the temperature of the melting substance. When a correction is made the fact is noted thus, 205° (corr.). The number of degrees which must be added to the observed temperature is found from the formula $N(t - t')0.000154$, in which N is the number of degrees of mercury outside the bath, t the observed temperature, and t' the average temperature of the stem outside the bath. The number 0.000154 is the coefficient of expansion of mercury in glass.

The melting point of a substance is a valuable criterion of its purity and is much used in the study of organic compounds. The effect of an impurity in a substance on its melting point is to cause the substance to melt over a certain range of temperature which is usually below the point where it melts sharply when pure. For example, an impure sample of benzoic acid melted at 116° to 119°, whereas the pure substance melts at 121.7°. An impurity usually lowers the melting point even if the impurity melts at a higher temperature than the substance itself. Thus, if triphenylmethane, which melts at 92.5°, is mixed with about one-fourth its weight of benzoic acid, which melts at 121.7°, the melting point of the mixture becomes 79° to 83°. The student is no doubt familiar with this principle in other cases, such

as the influence of dissolved substances on the freezing point of water.

6. Cooling Curves.—When it is desirable to know the melting point of a substance with a high degree of accuracy, or to determine definitely the presence or absence of an impurity in a sample of a compound, a cooling curve of the substance is made. This is accomplished by placing a thermometer in several grams of the melted substance, contained in a test tube, and noting at definite

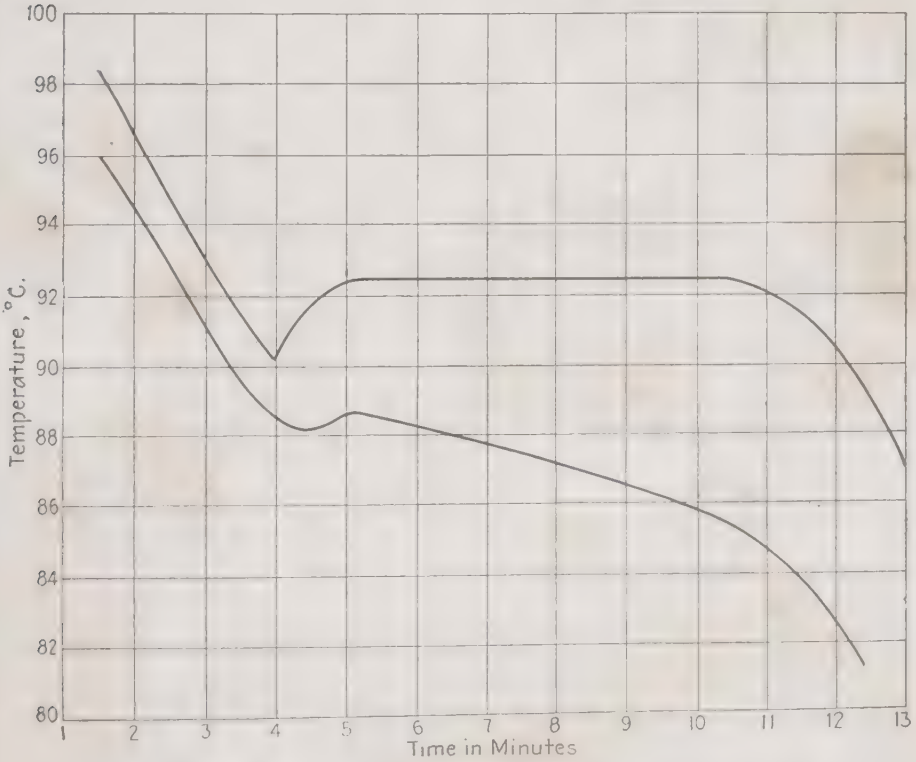


FIG. 1.

time intervals the temperatures recorded until the substance has solidified. The results are plotted, using as coordinates temperature and time. The accompanying diagram (Fig. 1) shows the curves obtained in this way in the case of a pure substance, and the same substance mixed with a small amount of another compound.

The horizontal part of the upper curve in Fig. 1 shows the temperature at which the liquid and solid phases are in equilibrium—

the melting point. The absence of such a flat part in the lower curve is evidence that the substance used was impure.

In order to prevent rapid cooling, the tube containing the substance is protected from the air by cotton wool, or a tube provided with a vacuum jacket is used. To prevent too much supercooling and to insure equilibrium the substance is stirred with the thermometer until solidification takes place.

7. Determination of Boiling Points.—In the case of liquids the boiling point serves as a criterion of purity. The liquid is heated to boiling in a flask connected with a condenser, and the temperature noted as soon as the vapor begins to condense freely. The temperature is observed from time to time until only a small quantity of liquid remains in the flask. In the case of a pure substance the temperature remains constant during the distillation. If the substance contains two or more compounds which are volatile, the temperature will rise as distillation proceeds. The temperature at which the vapor begins to condense and that observed when the distillation is stopped are taken as the boiling point of that portion of the liquid which has been distilled. It is necessary to note the two temperatures indicated, as taken together they serve as a valuable criterion of purity. Thus, a sample of benzene which boils at 80° to 84° contains an appreciable amount of other substances. In determining the purity of a liquid it is distilled, and if the boiling point is found to be constant it may, in general, be assumed to consist of but a single compound and be, therefore, pure.[1]

As changes in the pressure of the atmosphere affect the boiling points of liquids, both the temperature and pressure are frequently recorded, thus, 220° (750 mm.). When no pressure is specified, the normal pressure, 760 mm., is understood. When the boiling point is taken at a pressure not far from this, a close approximation of the boiling point at 760 mm. may be obtained by applying a correction of 0.1° for each 2.7 mm. pressure. If the observed pressure is less than 760 mm. the correction should be added, and if greater it should be subtracted. A correction for stem exposure should be made in the way described under the determination of melting points.

[1] A number of mixtures which have constant boiling points are known. The student is familiar with such a mixture of hydrochloric acid and water, and will recall the fact that the composition of the mixture may be varied by changing the pressure under which the distillation is effected. Mixtures of organic compounds are known which behave in a similar manner.

8. Boiling-point Curves.—When the purity of a liquid is to be tested it is advisable to make a boiling-point curve. The distillate is collected in a graduated cylinder and from time to time the temperature of the thermometer and the volume of the liquid which has distilled are recorded. A plot of the results is made using as coordinates temperature and volume (Fig. 2).

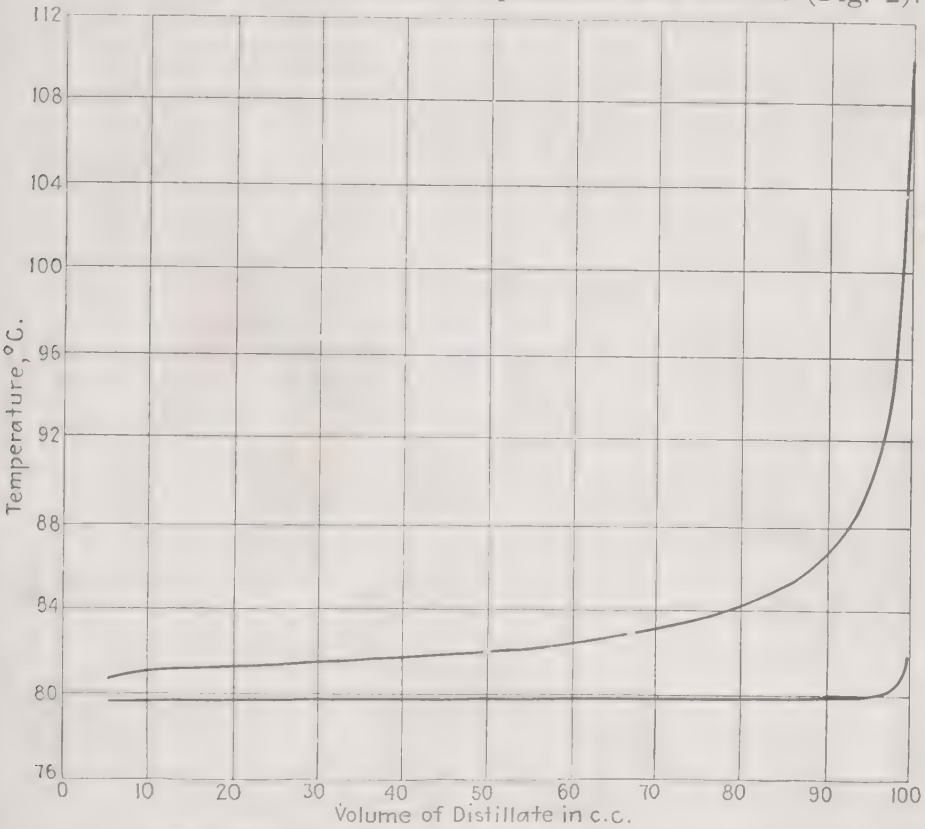


FIG. 2.

PURIFICATION OF ORGANIC COMPOUNDS

9. Crystallization.—A substance which crystallizes and melts without decomposition can be purified in the following manner: The substance is melted and then allowed to cool slowly. When a large part has solidified the crystals are separated from the liquid by draining or washing with a solvent. This process may be repeated until a pure compound results. Benzene and acetic acid are frequently purified in this way.

The method is based on the fact that when a slightly impure liquid freezes, the pure compound first separates as pure crystals from a more concentrated solution of the impurity, which, as a consequence, has a lower freezing point. The separation of pure water in the form of ice from a solution of salt in water is a familiar example.

Although the process just described is efficient, it is wasteful, and crystallization from a solvent is usually used. The substance to be purified is dissolved in a liquid from which it will separate as crystals, either on spontaneous evaporation or when the warm, saturated solution cools. Separation of a pure compound from a mixture usually can be effected in this way, as the solubilities of the constituents of the mixture in the solvent will be different, and the least soluble substance will separate first. The melting point of the crystals which separate is determined. If this point is not sharp, the substance is recrystallized and the melting point redetermined. The process is repeated as long as recrystallization brings about a rise in melting point. The substance is considered pure when recrystallization does not affect the melting point. In order to obtain a substance in the pure condition quickly, it is well to select for the solvent, if possible, a liquid in which the impurity present is much more soluble than the substance to be purified.

10. Fractional Distillation.—When a mixture of two liquids which boil at different temperatures is distilled, the temperature of the vapor during the distillation rises in most cases from the boiling point of one of the liquids to that of the other. The distillate which is collected at first contains a large proportion of the lower-boiling liquid, while that collected toward the end of the operation is rich in the higher-boiling liquid. In order to separate the two, the mixture is subjected to what is called fractional distillation.

The process is carried out in the following way: The mixture is distilled slowly, and the receiver in which the distillate is collected is changed from time to time, as the boiling point of the liquid rises. In this way the mixture is separated into what are called fractions. The number of fractions collected and the limits of the boiling point of the various fractions are determined by the difficulty of separating the mixture and the purity of the

products desired. The lowest-boiling fraction is next placed in a clean flask and distilled. When the temperature reaches that of the upper limit of the fraction the heating is stopped, and the second fraction added to the flask. Distillation is then continued until the upper limit of this fraction is reached, the distillate being collected in the appropriate receiver. The process is continued in this way until all the fractions have been distilled a second time. It will be found as a result of this fractionation that the distribution of the liquid in the several fractions is different from that obtained the first time. The fractions which boil at temperatures near those of the boiling points of the constituents of the mixture increase in volume. By repeating the process a sufficient number of times, practically all the liquid can be separated into its constituents.

In the following table are given the results of the fractional distillation of a mixture of 50 c.c. of methyl alcohol and 50 c.c. of water. The volumes of the fractions obtained after each of six fractionations are recorded.

	66° to 68°	68° to 78°	78° to 88°	88° to 98°	98° to 100°
I	0.0	1.5	47.0	17.0	31.0
II	0.0	33.5	14.0	7.5	38.5
III	1.5	38.5	6.5	5.5	40.5
IV	15.0	24.5	5.0	3.0	43.5
V	25.0	16.0	2.5	1.0	44.5
VI	32.0	7.5	1.0	0.0	45.5

When two liquids form a constant-boiling mixture, they can not be separated in pure condition by fractional distillation. The boiling point of a mixture of ethyl alcohol and water which contains 96 per cent by weight of the former is lower than that of pure alcohol. As a consequence, when a mixture of the two substances is subjected to repeated fractional distillation, the constant-boiling mixture is obtained. In order to prepare pure alcohol it is necessary to remove the water from the mixture by chemical means. Very few cases of this kind are met with in the purification of organic compounds.

Many substances which decompose when heated to their boiling point under atmospheric pressure distill unchanged when

the pressure is reduced. The purification of such substances is conveniently effected by distilling them under diminished pressure. In order to do this, the vessel in which the distillate is collected is connected with a pump which removes the air from the apparatus.

Substances which have an appreciable vapor pressure at 100° can be separated from those which do not by passing steam through the mixture and condensing the water vapor, which carries along with it the vapor of the volatile substance.

Methods of Analysis

11. Qualitative Analysis.—After a substance has been obtained in a pure condition, the next step in its study is the qualitative determination of the elements of which it is composed. This is, in general, a simple process compared with the analysis of inorganic substances, as most organic compounds contain but a few elements, which are easily recognized. Many compounds contain carbon and hydrogen alone; still more contain these elements together with oxygen. Nitrogen, sulphur, and the halogens are frequently present, and a few compounds contain phosphorus, arsenic, boron, silicon, and similar elements.

The presence of *hydrogen* and *carbon* in organic compounds can be shown by heating them with copper oxide. The oxide is reduced, and carbon dioxide and water are formed. The carbon dioxide may be detected in the usual way with lime water. The water formed will condense in the cold part of the tube in which the decomposition is effected.

When the non-metals are joined to carbon they do not show the reactions with which the student is familiar, on account of the fact that the compounds containing them are in most cases not ionized. In detecting these elements it is necessary, therefore, to convert them into compounds in which their presence can be discovered by the usual tests. This can be done by heating the compound to be analyzed with sodium. When decomposition has been effected in this way the non-metallic elements unite with the sodium, and sodium chloride, phosphide, sulphide, etc., are formed. If nitrogen is present it is found as sodium cyanide. The presence of these substances is detected by the methods of inorganic qualitative analysis.

A convenient and delicate way of detecting halogen in an organic compound is to introduce into the flame of a Bunsen burner a little of the substance on the end of a copper wire which has been previously cleaned by heating until it imparts no color to the flame. A halide of copper is produced, which volatilizes with the production of a brilliant green color.

12. Quantitative Analysis.—The determination of the percentage composition of a pure compound is called *ultimate analysis*. The methods used in ultimate organic analysis are simple in principle, but their successful application requires close attention to many details. Only the outlines of the process will be given here.

Carbon and *hydrogen* are estimated by burning a known weight of the substance and weighing the carbon dioxide and water formed. The substance to be analyzed is heated in a tube of hard glass through which oxygen is passed. In order to ensure complete combustion, the gases formed are passed over copper oxide which is kept at a dull-red heat. The products of combustion are passed, first through a tube containing calcium chloride which absorbs the water, and then through a tube containing a solution of potassium hydroxide which absorbs the carbon dioxide. If nitrogen is present, the products of combustion are passed over heated copper in order to reduce the oxides of nitrogen formed during the combustion. If the oxides of nitrogen were allowed to pass through the tubes used to collect the water and carbon dioxide, they would be absorbed, and the increase in weight in the tubes could not be used in calculating the amount of hydrogen and carbon in the compound analyzed. If a halogen is present in the substance burned, the gases are passed over heated silver foil.

Nitrogen may be determined conveniently in two ways. The *Dumas method*, commonly used, consists in burning the substance with copper oxide in a stream of carbon dioxide. The gases produced are passed over hot copper to reduce the oxides of nitrogen formed, and, finally, the volume of the nitrogen is measured, after the carbon dioxide present has been absorbed by a solution of potassium hydroxide. This is called the *absolute method*.

The *Kjeldahl method* for the determination of nitrogen is the one generally used in the analysis of food products and other

complex mixtures. The substance to be analyzed is heated with concentrated sulphuric acid until it is completely oxidized. The nitrogen present is converted into ammonia which unites with the excess of sulphuric acid to form ammonium sulphate. The amount of ammonia formed is determined by treating the mixture of the acid and ammonium salt with an excess of sodium hydroxide, and distilling. The aqueous distillate which contains the ammonia is collected in a solution of a known quantity of acid. The difference between this amount of acid and that which is present after the ammonia has been absorbed is a measure of the ammonia formed, and consequently of the nitrogen in the compound analyzed. The oxidation of the substance by sulphuric acid is facilitated by adding potassium sulphate, mercury, or other substances.

Sulphur is usually determined by the method described by Carius. The substance is heated in a sealed tube with fuming nitric acid, and the sulphuric acid so formed is precipitated as barium sulphate. The method for the *halogens* is similar. In this case silver nitrate is present in the tube during oxidation, and the silver halide formed is determined.

As the methods for determining *oxygen* are not entirely satisfactory, the percentage of this element is usually estimated by subtracting the sum of the percentages of the other elements present from 100.

It is often necessary in the analysis of a mixture of compounds to determine the proportions in which the constituents of the mixture are present. Many natural products used as foods or drugs, or in the manufacture of paints, dyes, etc., are mixtures in which compounds of known composition are present in varying proportions. Thus, milk contains water, fat, inorganic salts, and organic nitrogen compounds. The quantitative determination of the constituents of such mixtures is called *proximate analysis.* Many methods have been applied in this branch of quantitative analysis. They are based on the physical and chemical properties of the compounds which constitute the mixtures. A few typical methods are described in the chapter in which fats and oils are discussed.

Empirical and Molecular Formulas

13. The student is familiar from the study of inorganic chemistry with the methods used in expressing the composition of a compound by means of a formula. The formula SiO_2 means that silicon dioxide contains silicon and oxygen in the proportion one gram-atomic weight (28.3) of the former to two gram-atomic weights (32) of the latter. Such a formula, in which only the weight relations of the constituents of a compound are expressed, is called an *empirical formula*. In the case of many inorganic compounds it is possible to apply the molecular hypothesis. When this can be done, the formula expresses not only the weight relations but the number of atoms of each element which constitute the molecule. Such a formula is called a *molecular formula*. Thus, the symbol H_2O signifies not only that water contains 2 parts of weight of hydrogen to 16 parts of oxygen, but that in the gaseous condition its molecule consists of two atoms of hydrogen and one of oxygen.

14. Determination of Empirical Formulas.—The method of determining the empirical formula of an organic compound from the results of its analysis is illustrated by the following example: A substance was found to contain 37.42 per cent carbon, 12.70 per cent hydrogen, and 49.88 per cent oxygen. This means that 100 grams of the compound contains 37.42 grams of carbon, 12.70 grams of hydrogen, and 49.88 grams of oxygen. In this statement the weights of the elements are all expressed in the same unit, namely grams. In a chemical formula the unit of weight is different for each element. When carbon is considered, for example, the unit is expressed by the letter C, which represents an atomic weight of the element. As 100 grams of the compound under consideration contains 37.42 grams of carbon, and as each unit of carbon weighs 12 grams, there are $37.42 \div 12$, or 3.11 units of carbon present. In the same way we find there are $12.70 \div 1$, or 12.70 units of hydrogen, and $49.88 \div 16$, or 3.10 units of oxygen. The compound thus contains carbon, hydrogen, and oxygen in the proportion of 3.11:12.70:3.10, respectively, if the unit of measure in each case is the atomic weight of the element. These numbers are approximately in the ratio of 1:4:1, and the empirical formula of the compound is CH_4O.

It is evident that any error in the percentage composition as determined by analysis affects the numbers obtained by dividing the percentages by the atomic weights. As all quantitative analyses are only close approximations to truth, we have a right to reduce ratios obtained as above to the smallest whole numbers which express these ratios within the degree of accuracy of the methods of analysis employed.

It will be seen from the above that in calculating the empirical formula of a compound the percentage of each element is first divided by its atomic weight; the smallest whole numbers are selected which are in the same ratio as the numbers so found, and finally a formula is written in which the number of atoms of each element present is the number found by the above calculation in each case.

In order to determine whether the formula so deduced is correct within the limits of error of the analysis made, the theoretical percentage composition of a compound having this formula should be calculated. In the example given, a compound having the formula CH_4O contains 12 parts by weight of carbon, 4 of hydrogen, and 16 of oxygen. In 32 parts of the compound there are, accordingly, 12 parts of carbon. Twelve thirty-seconds, or 37.50 per cent, of the compound is carbon. The percentages of oxygen and hydrogen are 50.00 and 12.50, respectively. The numbers obtained by analysis agree with these well within the limits of error of the methods used, and the calculated formula is consequently in accord with the facts.

Determination of Molecular Weights

15. A quantitative analysis of a compound tells us only the proportion by weight in which the elements are present in the compound. When we interpret these figures, using the conception of atoms of definite weight, we arrive at a formula which expresses the proportion in which the atoms present are combined. In the case of the compound studied in the last section, the formula arrived at was CH_4O. We cannot determine by analysis whether the correct formula is the one given or some multiple of this, such as $C_2H_8O_2$ or $C_3H_{12}O_3$, as the percentage composition of all such compounds is the same. It is evident, therefore, that we must study some property of the compound in question

which will enable us to decide which multiple is the correct one. The property selected is the molecular weight. The molecular weights of substances having the formulas given above are different. If CH_4O is correct the molecule weighs 32; if there are two atoms of carbon, it weighs 64, etc. A number of methods have been devised to determine molecular weights. A few of the more important ones will be described briefly.

The *method of Dumas* is based on Avogadro's principle that equal volumes of gases contain the same number of molecules, when the gases are measured under the same conditions of temperature and pressure. How this principle is applied is evident from the following consideration: Suppose 1 liter of hydrogen and 1 liter of the vapor of a substance the molecular weight of which is sought, are weighed separately under the same conditions, and it is found that the vapor weighs sixteen times as much as the hydrogen. All the molecules of the vapor weigh sixteen times as much as all the molecules of the hydrogen, and since there are the same number of each, it follows that each molecule of the vapor weighs sixteen times as much as each molecule of hydrogen. For reasons which are familiar to the student, the molecular weight of hydrogen is taken as 2, as it can be shown that the molecule contains at least two atoms. The molecular weight of the substance under discussion is, therefore, 32. The molecular weight, accordingly, is equal to the vapor density compared with hydrogen multiplied by 2. In carrying out the method it is only necessary to weigh a known volume of the substance in the gaseous condition at a convenient temperature and pressure. By an application of the gas laws the volume is reduced to 0° and 760 mm. pressure, and the ratio between the weight found and the weight of an equal volume of hydrogen is calculated. Twice the density so determined is the molecular weight.

In the *method of Victor Meyer* the density is determined by finding the volume of the vapor produced from a known weight of substance. As this can be done more readily than the weight of a known volume of vapor can be determined, the method has largely replaced that of Dumas.

16. Determination of Molecular Weight from the Boiling Point and Freezing Point of Solutions.—In order to determine

the molecular weight of a compound by either of the methods just described, it is necessary to vaporize the substance. The methods are not applicable, therefore, to the large number of substances which cannot be boiled without decomposition. The molecular weight of such substances is determined by methods which are based on the effect of dissolved substances on the boiling point or freezing point of liquids. These methods are generally applicable, and are often used instead of the method of Victor Meyer, especially in the case of substances which boil at high temperatures.

The study of the effect of a dissolved substance on the boiling point of a liquid has shown that *the rise in the boiling point of a solvent produced by dissolving in it a non-ionized substance is proportional to the weight of the substance dissolved, and inversely proportional to the weight of the solvent and to the molecular weight of the dissolved substance.* These facts are expressed by the formula

$$\triangle = C \frac{S}{S' \times M}$$

where

$\triangle$ = rise in boiling point
S = weight of substance
S′ = weight of solvent
M = molecular weight of substance
C = a constant

The value of C can be found for a solvent by determining the rise in boiling point produced by dissolving a definite weight of a substance of known molecular weight in a definite weight of the solvent. For example, it has been found that when 0.625 gram of a substance having a molecular weight of 123 is dissolved in 20 grams of benzene, the boiling point of the latter is raised 0.694°. If we substitute these values in the formula we have

$$0.694 = C \frac{0.625}{20 \times 123}$$

From this we find that C is 2.730. This is the value found for C whenever the solvent used is benzene. It is called the constant for benzene. In a similar way constants for other solvents can be found.

The equation given above can be changed into the form

$$M = \frac{C \times S}{S' \times \triangle}$$

If the constant for the solvent is known, it is evident that an unknown molecular weight can be determined by observing the change in boiling point of the solvent produced by dissolving in it a known weight of substance. For example, the rise in the boiling point of benzene was 0.200° when 0.232 gram of a certain substance was dissolved in 18 grams of the solvent. The molecular weight can be found by substituting these values in the formula:

$$M = \frac{2{,}730 \times 0.232}{18 \times 0.200} = 176$$

The determination of molecular weights by means of the depression of the freezing point is based upon the same principle as that underlying the determination by means of the rise in boiling point. The same laws hold. The constants, however, for the various solvents are not the same as those used in calculating molecular weights by the boiling-point method.

In the experiment quoted to illustrate the method of finding the constant for benzene, 0.625 gram of a substance with the molecular weight 123, when dissolved in 20 grams of benzene, caused a rise in the boiling point of 0.694°. If the freezing point of this solution is taken it will be found to be 1.301° lower than that of the solvent. From this we can calculate, as before, the constant for benzene when the depression of the freezing point is used to determine molecular weights:

$$1.301 = C \frac{0.625}{20 \times 123}$$

From this equation we find that C = 5,120. The equation for calculating molecular weights is the same as that given above; in this case, however, $\triangle$ signifies the depression of the freezing point and C is the freezing-point constant for the solvent used.

The constants calculated as above bear a simple relation to what are called the molecular elevation of the boiling point and the molecular depression of the freezing point. These quanti-

ties are the elevation of the boiling point and the depression of the freezing point produced by dissolving 1 gram-molecular weight of any substance in 100 grams of the solvent. If we take the equation

$$\triangle = C\frac{S}{S' \times M}$$

and make S = M and S′ = 100 we have,

$$\triangle = C\frac{M}{100\ M} = \frac{C}{100}$$

The values for these quantities for a few solvents are given in the following table.

Solvent	Molecular depression of freezing point	Molecular elevation of boiling point
Water	18.5	5.2
Benzene	51.2	27.3
Phenol	74.0	30.4
Ethylene bromide	118.0	64.3

It is seen that the depression of the freezing point is greater than the elevation of the boiling point. On this account the determination of molecular weights by the freezing-point method is often preferred.

Structure of Organic Compounds. Isomerism

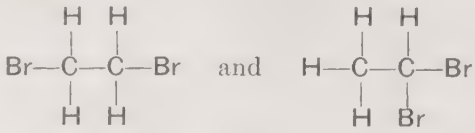
17. The methods used in the study of organic compounds which have been outlined up to this point make it possible to write formulas for many substances which express their composition and molecular weight. It is the endeavor of chemists, however, to represent more than this by the formula of a compound. Thus, lead nitrate is written $Pb(NO_3)_2$ and not PbN_2O_6, in order to show clearly that the compound is related closely to nitric acid. In the case of most inorganic compounds little more is expressed by the formulas than percentage composition. Chemists have succeeded, however, in expressing in the formula

of an organic compound many of the chemical properties possessed by the substance. This enlargement of the original meaning of a formula grew out of the necessity of distinguishing in some way between compounds which have the same percentage composition and molecular weight.

There are many organic compounds which have the same percentage composition and molecular weight; for example, 107 compounds having the formula $C_9H_{11}NO_2$ have been described. Such compounds are called *isomers* (signifying equal measure) and the phenomenon is known as *isomerism*. Compounds which have the same percentage composition but different molecular weights are classed as *polymers*. Benzene, C_6H_6, is a polymer of acetylene, C_2H_2. In this case the molecular formulas are different and there is no confusion, but in the case of isomeric substances the formulas for all are the same. There are two substances, for example, which have the composition and molecular weight represented by the formula C_2H_6O. It is evident that the formula must be written in two ways if there is to be a distinct way of representing each compound. In this particular case one of the substances shows many of the properties of a hydroxide. This fact is emphasized by writing for it the formula $C_2H_5.OH$. The other compound is an oxide. This is shown by writing for it the formula $(CH_3)_2O$. Such formulas are sometimes called rational formulas.

It is evident that it is desirable to express as many facts as possible in the formula of a compound, and chemists have elaborated a valuable system of expressing the properties of substances in their study of organic compounds. This system has resulted from a special application of the theory of the atomic and molecular constitution of matter to organic compounds. In seeking an explanation of the phenomenon of isomerism chemists came to the conclusion that, if the molecules of two substances contain the same number and kinds of atoms in the same relative proportions, the difference between the two must be caused by a difference in arrangement of the atoms within each molecule. There are, for example, two compounds which have the formula $C_2H_4Br_2$. Two possible arrangements of the atoms in a molecule of this composition immediately suggest themselves. In one each carbon atom holds in combi-

nation with itself one bromine atom, and in the other both bromine atoms are joined to the same carbon atom. These arrangements could be represented thus:



Formulas such as these, in which each combining power of the elements is represented by a line, are called *graphic formulas*. When a formula is written in a more condensed form, such as $BrCH_2.CH_2Br$ or $H_3C.CHBr_2$, which, however, expresses the facts indicated by the graphic representation, it is called a *structural* or *constitutional formula*.

18. A large part of the work in organic chemistry has had to do with the theory of arrangement of the atoms in molecules. Until recently this theory has not been made use of to any great extent in the study of inorganic compounds. On account of the greater simplicity of most of these compounds and the almost total lack of isomerism, it has not been necessary to consider the arrangement of the atoms in the molecule in order to account for the properties and reactions of compounds. The great advance in organic chemistry, however, and the success which has been attained in the building up of many important substances, have been the direct result of the extension of the atomic and molecular hypothesis to a consideration of the arrangement of the atoms in molecules.

For many years conclusions as to how the atoms are joined together in any compound were reached from an interpretation of the way in which the compound reacts with other substances; the problem was attacked by chemists. In recent years the methods of physics have been applied to this important subject. By the use of x-rays and the study of absorption spectra definite conclusions have been reached in regard to the structure of the molecules of a large number of substances. These results confirm in a striking way the conclusions from chemical evidence. They also yield significant facts that had not been discovered by the use of chemical means of investigation.

Problems

1. Calculate the percentage composition of (*a*) C_4H_{10}; (*b*) $C_5H_{12}O$; (*c*) $C_6H_4ClNO_2$.

2. Calculate the empirical formulas of the substances which yielded the following percentage results when analyzed: (*a*) C, 81.82 and H, 18.18; (*b*) C, 92.10 and H, 7.75; (*c*) C, 31.05; H, 15.65; and N, 31.16.

3. A qualitative analysis of a compound showed that it contained sulphur and no other elements except carbon and hydrogen. An analysis for the latter elements gave the following percentage results: C, 38.70 and H, 9.68. Calculate the formula of the compound.

4. A substance was found on analysis to contain 83.40 per cent of carbon and 16.70 per cent of hydrogen. In a determination of the vapor density of the substance it was found that 100 c.c. of the gas when reduced to 0° and 760 mm. pressure weighed 0.324 gm. Calculate the molecular formula of the compound.

5. An analysis of a compound which contained carbon and hydrogen gave the following results: Weight substance 0.2500 gm. gave 0.7697 gm. CO_2 and 0.3605 gm. H_2O. In a determination of the molecular weight by the Victor Meyer method 0.3070 gm. of the substance gave 80.5 c.c. vapor at 25° and 730 mm. pressure. Calculate (*a*) the percentage composition, (*b*) the empirical formula, and (*c*) the molecular formula of the compound.

6. An analysis of a compound which contained nitrogen gave the following results: 0.6137 gm. substance gave 54 c.c. N_2 measured over water at 17° and 744 mm. pressure (tension of water vapor at 17° is 14 mm.). (*a*) Calculate the percentage of nitrogen in the compound. (*b*) What would be the volume of the gas if the water vapor were removed?

7. When 0.460 gm. of a substance was dissolved in 17 gm. of benzene the boiling point of the solution was raised 0.391°. Calculate the molecular weight of the compound.

8. When 0.620 gm. of a substance was dissolved in 15 gm. of water the freezing point was lowered 0.102°. Calculate the molecular weight of the compound.

9. Ether boils at 34.5° and has the molecular formula $C_4H_{10}O$ and the density 0.719 at 17°. (*a*) Calculate the volume of the vapor produced from 1 gm. of ether at 100° and 760 mm. pressure. (*b*) Calculate the volume of the vapor at 40° and 760 mm. pressure from 10 c.c. of ether.

CHAPTER II

HYDROCARBONS OF THE METHANE SERIES

19. Classification of Hydrocarbons.—In a systematic study of the compounds of carbon it is advisable to begin with a consideration of the compounds which contain hydrogen and carbon only. These substances, which are called hydrocarbons, occur in nature, are formed in certain industrial processes, and have important uses. It is not for these reasons, however, that the hydrocarbons are first studied. They are, perhaps, the simplest organic compounds, and a knowledge of their properties and reactions is the best preparation for the study of more complex substances. Further, most compounds can be considered as derived from the hydrocarbons by the replacement of one or more hydrogen atoms by other atoms or groups of atoms.

A large number of hydrocarbons are known. Their study is greatly simplified by the fact that it is possible to classify them into a small number of groups. *This classification of the hydrocarbons is based on their chemical properties, which are largely determined by the relation between the number of carbon and hydrogen atoms in the molecule.* Thus, a great many hydrocarbons are very inert when brought into contact with other substances. They are not appreciably affected by concentrated sulphuric acid and nitric acid, and resist the action of strong alkalies and most oxidizing agents. Chlorine and bromine react with these hydrocarbons under certain conditions, and the hydrogen which they contain is replaced by halogen. Certain hydrocarbons which show these properties are called paraffins (from Latin *parum affinis*, small affinity) and are said to belong to the methane series, as methane, CH_4, is the simplest member of the group. Among the hydrocarbons in this series are ethane, C_2H_6, propane, C_3H_8, and octane, C_8H_{18}. It will be seen that the number of hydrogen atoms in each compound is two more than twice the number of carbon atoms. The general formula for the members of the series is C_nH_{2n+2}.

Other hydrocarbons are much more reactive than the paraffins; some unite directly with the halogens and with the halogen acids. Ethylene, C_2H_4, propylene, C_3H_6, and octylene, C_8H_{16}, belong to a series the members of which show these properties. These hydrocarbons each contain two less hydrogen atoms than the paraffin with the same number of carbon atoms. The general formula for this series is C_nH_{2n}.

One more example will be given. There are a number of important hydrocarbons which form characteristic compounds when they are treated with sulphuric acid or with nitric acid. Benzene, C_6H_6, toluene, C_7H_8, and xylene, C_8H_{10}, are examples. The general formula for these hydrocarbons is C_nH_{2n-6}.

20. Methane, CH_4, the first member of the paraffin series, is the only hydrocarbon which contains but one carbon atom. It is a colorless and odorless gas, slightly soluble in water, and has the specific gravity 0.559 compared with air. Its molecular weight is less than that of any other compound, and it is consequently the lightest compound gas known. Liquid methane boils at $-161.4°$ and solidifies at $-184°$.

Methane is produced as a result of the decomposition of many complex organic substances. It is formed when dead vegetable matter, such as leaves, grass, etc., undergoes disintegration under water in stagnant pools. For this reason it is called "marsh gas." The gas which rises in bubbles when a mass of decaying leaves is stirred, is a mixture of methane, nitrogen, and carbon dioxide. Experiments in the laboratory indicate that the decomposition is brought about by the micro-organisms which breed in stagnant water. The chief constituent of leaves and other vegetable matter is a compound called cellulose. It has been shown that when filter paper, which is pure cellulose, is subjected to the action of the bacteria in sewage, methane is one of the products of the decomposition which takes place.

Other natural processes bring about the formation of this hydrocarbon. The intestinal gases which are formed as the result of the imperfect digestion of foods contain at times as much as 56 per cent of methane. The compound occurs in coal mines, and on account of the fact that it burns it is called by miners "fire damp"; its presence in coal mines often leads to

destructive explosions. Mixtures of the gas and air in certain proportions (from 5 to 13 per cent of methane by volume) explode violently when ignited.

Natural gas contains about 90 per cent methane. The method of the formation within the earth of large quantities of methane has aroused the interest of chemists. Some hold the view that the gas is formed as the result of the action of heat on vegetable substances, while others are of the opinion that animal remains are the source of the gas. The subject will be discussed more fully when the theories as to the formation of petroleum are considered (**33**).

Illuminating gas contains methane. It is present to the extent of between 30 and 40 per cent in coal gas. Carburetted water gas contains 10 to 15 per cent methane. The hydrocarbon is produced in the latter case during the process of enriching, which consists in heating water gas to a high temperature with a mixture of liquid hydrocarbons. At the temperature to which the mixture is heated the hydrocarbons undergo decomposition, and gaseous compounds are formed. These consist largely of methane as this hydrocarbon resists to a high degree the action of heat. Most hydrocarbons when heated to the point of decomposition are converted largely into methane.

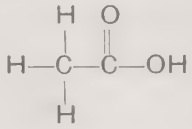
21. Preparation of Methane.—Methane can be prepared in a number of ways in the laboratory. Of theoretical interest is the fact that it is formed in small quantities when carbon is heated with hydrogen at 1200°. If an active form of carbon made by burning methane in an insufficient supply of air (so-called "gas black") is used, and finely divided nickel is employed as a catalyst, union of the carbon and hydrogen takes place at a much lower temperature. At 475° the gases in contact with the carbon contain 51 per cent of methane when equilibrium is reached. Nickel serves as an excellent catalytic agent in reactions involving the addition of hydrogen to carbon compounds; it also catalyzes at higher temperatures the removal of hydrogen from these compounds.

Methane is formed when a mixture of hydrogen and carbon monoxide or carbon dioxide is passed over finely divided nickel at about 250°.

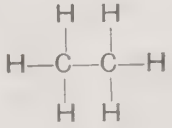
The compound is also formed when aluminium carbide is treated with water:

$$Al_4C_3 + 12H_2O = 4Al(OH)_3 + 3CH_4$$

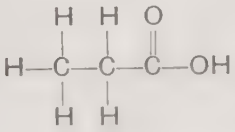
A convenient laboratory method of preparing methane is to heat sodium acetate with soda lime, which is a mixture of sodium and calcium hydroxides. As organic acids or their salts are frequently used in the preparation of other compounds, it is well at this point to give a few facts about them. Acetic acid, which is described in detail in Sec. **107,** is the acid contained in vinegar. It has the structure represented by the formula



and may be considered as derived from methane by the replacement of a hydrogen atom by the group —C(=O)—OH. This group is present in many organic acids, and on account of its frequent occurrence has been given the name *carboxyl*. The acids, in general, may be considered as derived from hydrocarbons by the replacement of hydrogen by carboxyl. The acid derived from ethane



has the formula



The structural formulas of these acids are usually written $CH_3.COOH$, $C_2H_5.COOH$, etc.

The preparation of methane from acetic acid can now be understood more readily. To obtain the hydrocarbon it is necessary to replace the carboxyl group by a hydrogen atom.

This is accomplished by melting the salt of the acid with an alkali. The reaction may be represented thus:

$$CH_3COONa + NaOH = CH_4 + Na_2CO_3$$

The reaction is of importance, not only because it furnishes a convenient way of preparing methane, but because it is an illustration of a general method used in the synthesis of organic compounds. *When the salt of an acid is heated to a high temperature with an alkali, the carboxyl group is replaced by hydrogen.* We can in this way convert most acids into the corresponding hydrocarbon. In certain cases the hydrocarbon formed is decomposed at the high temperature required to bring about the reaction. The methane prepared in this way is contaminated with small quantities of other substances, which are formed as the result of the action of heat on sodium acetate alone.

When a very pure sample of the hydrocarbon is desired, it is prepared by treating an alcoholic solution of methyl iodide, CH_3I, with a zinc-copper couple. In order to make clear this statement and others which are made later, the following facts are given at this point:

Methyl iodide is made by heating a concentrated aqueous solution of hydriodic acid with methyl alcohol:

$$CH_3OH + HI = CH_3I + H_2O$$

The relation between methane, CH_4, methyl alcohol, CH_3OH, and methyl iodide, CH_3I, is shown by other hydrocarbons and their analogous derivatives. The hydroxyl derivatives are called alcohols. Thus we have ethane, C_2H_6; ethyl alcohol, C_2H_5OH; and ethyl iodide, C_2H_5I. The group of carbon and hydrogen atoms, CH_3, C_2H_5, etc., which is present in such a series of compounds, is called a *radical*. The names of the radicals derived from the paraffins are formed from the name of the corresponding hydrocarbon by dropping the ending *ane* and adding the termination *yl*. For example, the alcohol derived from propane, C_3H_8, is called propyl alcohol, C_3H_7OH. Radicals of this type are called *alkyl* radicals as they are present in alcohols.

Methyl iodide can be obtained readily in a pure condition. It is a low-boiling, heavy liquid.

A practical method of converting methyl iodide into methane is to drop a solution of it in alcohol onto a zinc-copper couple.

The couple can be made by heating a mixture of 3 parts of granulated zinc with 1 part of powdered copper until the metals begin to alloy. In this form the metals are particularly active. The reaction consists in the formation of a compound of zinc and methyl iodide, which is subsequently decomposed by the alcohol itself, or by the water present in it. The reactions are as follows:

$$Zn + CH_3I = Zn\begin{<}CH_3\\I\end{>}$$

$$Zn\begin{<}CH_3\\I\end{>} + HOH = Zn\begin{<}OH\\I\end{>} + CH_4$$

By this method a slow and steady evolution of methane is produced. The gas contains a trace of methyl iodide vapor from which it must be separated. Magnesium may be used instead of zinc in the preparation of methane from methyl iodide. When the metal is warmed with the iodide a vigorous reaction takes place and methylmagnesium iodide, $Mg\begin{<}CH_3\\I\end{>}$, a colorless solid, is formed. With water this yields methane, magnesium hydroxide, and magnesium iodide.

22. Chemical Properties of Methane.—Methane is a very stable compound, and is inert when subjected to the action of most substances. The formation of methane as the result of the action of high heat on other hydrocarbons is further evidence of its stability. It is not affected by sulphuric, nitric, and other active acids, and can be heated with alkalies and powerful oxidizing agents without change.

Methane and Oxygen.—When methane is heated with oxygen to 670°, the mixture explodes, forming carbon dioxide and water vapor. The kindling temperature of methane is higher than that of hydrogen or amorphous carbon. Methane burns with a flame which is only slightly luminous. Its heat of combustion is high on account of the fact that it contains such a large proportion of hydrogen. The percentage of hydrogen in methane is greater than that in any other hydrocarbon. It is for this reason a valuable fuel. It must be enriched, however, before being used as an illuminant.

When methane is burned in an amount of air insufficient for complete combustion and the products are rapidly cooled, a small percentage of carbon is obtained. This is known as "carbon black" and is made in large quantities for use in automobile tires, paint, etc. Free carbon obtained by heating methane to a very high temperature is also manufactured for industrial use.

The equation which represents the volume relations and the amount of heat evolved when methane burns in oxygen, is as follows:

$$\underset{1\text{ vol.}}{CH_4} + \underset{2\text{ vol.}}{2O_2} = \underset{1\text{ vol.}}{CO_2} + \underset{2\text{ vol.}}{2H_2O} + 210{,}800\text{ cal.}$$

This equation means that one volume of methane reacts with two volumes of oxygen and forms one volume of carbon dioxide and two volumes of water vapor. If the latter condenses to the liquid state, the contraction when methane is exploded is from three volumes to one volume. In the case of other gaseous hydrocarbons the contraction is different in amount. The change in volume which takes place when hydrocarbons are exploded with oxygen serves as a means of identifying them and is the basis for their determination in gas analysis. The equation also means that the amount of heat given off when 16 grams of methane are burned, is 210,800 calories.

Methane and Halogens.—Chlorine and bromine react with methane and form products in which a part, or all, the hydrogen is replaced by halogen. Mixtures of chlorine and methane explode when exposed to direct sunlight. Hydrochloric acid, carbon, and compounds containing carbon, hydrogen, and chlorine are formed. The carbon is formed by the reaction,

$$CH_4 + 2Cl_2 = C + 4HCl$$

Reactions similar to this, in which chlorine removes all the hydrogen, are known in the cases of other hydrocarbons. When the violence of the reaction between chlorine and methane is reduced by mixing with the gases an inert gas, such as carbon dioxide, or by allowing the reaction to take place in diffused light, the hydrogen atoms in the hydrocarbon are replaced by chlorine. In this way compounds which have the formulas CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4 are formed. The replacement of one element by another, as in these cases, is called *substitution*.

The substances formed are called *substitution products.* The reaction by which methyl chloride is formed takes place according to the equation

$$CH_4 + Cl_2 = CH_3Cl + HCl$$

The substitution products of methane are called monochloromethane, dichloromethane, trichloromethane, and tetrachloromethane. In general, *in naming substitution products there is placed before the name of the hydrogen compound from which the product is derived a prefix formed from the name of the element which has replaced the hydrogen and the number of atoms which enter the compound.* Thus, the substance with the formula CH_2Cl_2 is called dichloromethane. In the case of many simple compounds other names than those derived in the way just indicated are used. Dichloromethane is often called methylene chloride. As the group CH_2 is present in a number of compounds it has been given the name methylene

Although chlorine and bromine react with methane and many other compounds and form substitution products, iodine does not show this power except under exceptional circumstances. The three halogens resemble one another in chemical properties, but there is a marked decrease in activity as we pass from chlorine to iodine. Chlorine and bromine react with hydrogen with the evolution of heat, whereas under the same conditions hydrogen iodide is formed with the absorption of heat. As the process of substitution involves the formation of a compound of the halogen and hydrogen, it is evident that the marked difference between the activity of chlorine and bromine on one hand, and that of iodine on the other, is an important factor in the reaction. From this point of view the reaction by which methane may be prepared from methyl iodide and hydriodic acid can be understood. The equation for the reaction,

$$CH_3I + HI = CH_4 + I_2$$

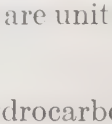
is the reverse of the one by which substitution takes place, namely,

$$CH_4 + Cl_2 = CH_3Cl + HCl$$

In the case of iodine the stable condition when reaction takes place is the hydrocarbon and the free halogen. In the case of

chlorine the reverse is true. We shall see later that hydrochloric acid and hydriodic acid are markedly different in the readiness with which they react with many organic compounds, and that the reactivity of the halogen atoms in organic compounds varies with the halogen.

23. Structure of Methane.—According to the structure theory of organic compounds, the molecule of methane consists of one carbon atom to which are united four hydrogen atoms. The graphic formula of the hydrocarbon is

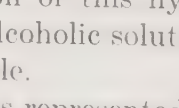


As a result of the study of many compounds the conclusion has been reached that the molecule is symmetrical; *i.e.*, all four hydrogen atoms bear the same relation to the carbon atom. It is conceivable that there might be differences in this relation among the hydrogen atoms. For example, one atom might be further removed from the carbon atom than the other hydrogen atoms, or be more loosely bound than the rest. An elaborate chemical investigation of this point, which cannot be discussed here, has shown that the hydrogen atoms in the molecule are symmetrically arranged with regard to one another and the carbon atom.

24. Ethane, C_2H_6, occurs in small quantities in natural gas and in solution in crude petroleum. It resembles methane in both chemical and physical properties, but is more readily liquefied. Liquid ethane boils at $-88.3°$.

Methods analogous to those used in making methane can be applied to the preparation of this hydrocarbon. It is usually prepared by treating an alcoholic solution of ethyl iodide, C_2H_5I, with the zinc-copper couple.

The *structure of ethane* is represented by the formula



This arrangement of the atoms is the only possible one if the assumption of the quadrivalence of carbon is accepted. There is, indeed, experimental evidence in favor of the correctness of

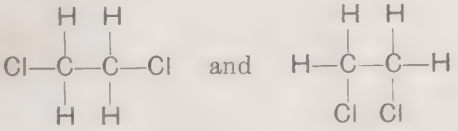
this view. A method by which the hydrocarbon may be prepared shows that ethane is made up of two methyl (CH_3) groups. Methyl iodide and sodium react and form ethane and sodium iodide:

$$2CH_3I + 2Na = CH_3—CH_3 + 2NaI$$

The simplest explanation of the change which takes place is that the metal removes the halogen atom from the iodide, and the methyl group which is formed unites with a second group to form ethane.

The view of the structure of ethane which has been reached in this way leads to the conclusion that all the six hydrogen atoms are alike in their relation to the carbon atoms. This has been found to be true, for although chloroethane, C_2H_5Cl, and other similar substitution products have been made in a number of ways, no case of isomerism among monosubstitution products has ever been discovered. The structure assigned to ethane does suggest, however, the possibility of the existence of two dichloroethanes, namely,

In one compound the chlorine atoms are united to different carbon atoms; in the other they are in combination with the same carbon atom. Two dichloroethanes are known, and we have reason to believe that they have molecular configurations in accordance with the formulas just given. From an examination of the graphic formulas of the dichloroethanes, it might appear that more than two compounds are possible. The formulas

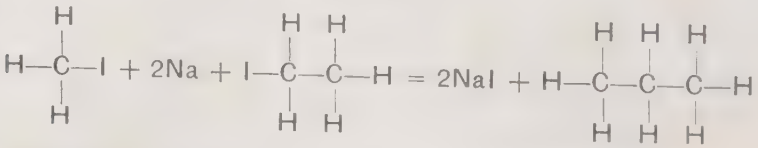


appear to be different. This is not the case, however, for it will be remembered that all the hydrogen atoms in methane, and therefore in a methyl group, are alike in their relation to the

carbon atom. This fact should be borne in mind in the study of more complicated substitution products which will be considered later. The necessity of writing formulas on a plane leads to apparent differences which do not exist among the compounds themselves.

The existence of the dichloroethanes has been mentioned at this point as their consideration serves to emphasize the methods used in establishing structural formulas. If we take ethane for an example the methods of preparing the hydrocarbon furnish facts which lead to a definite conclusion as to its structure. The conclusion reached in this way, however, must be tested further before it may be said to be well founded. We must deduce certain consequences which will follow if the view taken is the correct one. The more facts in accord with the theory, the more firmly is established the correctness of the assigned formula. It has been said that two dichloroethanes should exist if ethane has the formula assigned to it, and two are known. A study of the formula will lead to the conclusion that there should be two trichloroethanes, two tetrachloroethanes, one pentachloroethane, and one hexachloroethane. Just this number of chlorine substitution products exist. These facts strengthen markedly the conclusion that the structure of ethane is that which has been assigned to it.

25. Propane, C_3H_8, is a gas and shows the same inertness to chemical reagents as is shown by the other hydrocarbons of the methane series. It can be condensed to a liquid, which boils at $-44.5°$. The methods of preparation and properties of propane lead to the conclusion that it is a methyl derivative of ethane. It can be prepared by the action of sodium on a mixture of methyl iodide and ethyl iodide:

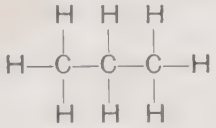


In this reaction the iodine atom in ethyl iodide is replaced by a methyl group. Reactions similar to this are much used in the synthesis of organic compounds. The building up of hydrocarbons in this way was first accomplished by Wurtz, a French

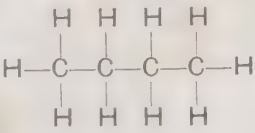
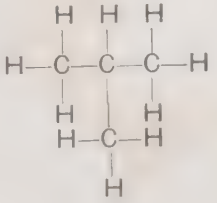
chemist, in 1855. The method is usually called the *Wurtz synthesis.*

Propane prepared in this way is mixed with ethane, which is formed by the action of sodium on methyl iodide, and with butane, C_4H_{10}, which results from the action of the metal on ethyl iodide. Propane is obtained in pure condition by the action of the zinc-copper couple on propyl iodide.

26. Butanes, C_4H_{10}.—There are two hydrocarbons which have the composition represented by the formula C_4H_{10}, and according to the structure theory there should be only two. We can consider the butanes as derived from propane by the replacement of one hydrogen atom by a methyl group, just as we considered ethane as methyl-methane, and propane as methyl-ethane. As all the hydrogen atoms in ethane are alike, but one methyl substitution product and, accordingly, one propane, is possible. Let us consider the possibilities if we replace one hydrogen atom in propane by a methyl group. The formula of propane is



An examination of the relation of the hydrogen atoms to the molecule shows that there is opportunity for isomerism. The hydrogen atoms which are joined to the end carbon atoms are alike in their position in the molecule. The two atoms which are in combination with the central carbon atom are alike, but differ from the other six hydrogen atoms in their relation to the molecule. It is evident, therefore, that two methyl derivatives are possible, and these should have the formulas,

(1)  and (2) 

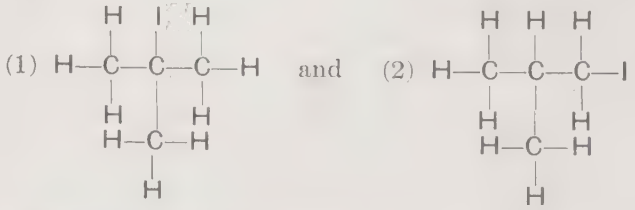
The substance having the structure represented by the first formula is called normal butane. The second formula is assigned

to isobutane. Hydrocarbons in which the carbon atoms are linked in what is called a chain, *i.e.*, where no carbon atom is joined to more than two carbon atoms, are called *normal hydrocarbons*. Such a structure is indicated by placing the letter *n* before the name of the hydrocarbon. When a carbon atom is joined to three other carbon atoms in the molecule, the compound is said to contain a *branched* chain; this fact is shown by prefixing to the name of the hydrocarbon the syllable *iso-*, which is derived from the word isomer.

Normal butane occurs in crude petroleum. It is a gas which can be readily condensed to a liquid, which boils at 0.6°. The liquefied hydrocarbon is now sold in cylinders and is used as a substitute for coal gas.

Butane can be prepared by the action of sodium on ethyl iodide. Its synthesis in this way leads to the conclusion that it has the structure represented by formula (1) above. The formula is usually written in the form $CH_3CH_2CH_2CH_3$.

Isobutane occurs in certain petroleums; it boils at $-10.2°$. It is prepared by the action of zinc and water on the butyl iodides of the formulas



The reactions are analogous to the one by which methane is made from methyl iodide and the zinc-copper couple. In the case of these iodides, however, zinc alone is capable of bringing about the reaction. Such formulas as the above are usually written, for convenience, in a more condensed form. In the molecule represented by the formula (1) there is one carbon atom to which are joined three methyl groups and one iodine atom. This fact is shown by the formula $(CH_3)_3CI$. Formula (2) can be written $(CH_3)_2CH.CH_2I$. It is important that the student should understand clearly the significance of these condensed formulas, as such formulas are generally used to express the structure of organic compounds.

27. Pentanes, C_5H_{12}.—As the number of carbon atoms in hydrocarbons increases, the opportunity for isomerism increases. The number of possible isomers and the arrangement of the atoms in the several molecules can be determined by the application of the principle made use of in deducing the butanes. The hydrocarbons of any formula may be considered as derived from the hydrocarbons containing one less carbon atom, by the replacement of hydrogen atom by a methyl group. Let us apply this method to determine the number of hydrocarbons of the formula C_5H_{12} which are possible. The butanes have the formulas

$$\text{(I) } \overset{(1)}{CH_3}\overset{(2)}{CH_2}\overset{(2)}{CH_2}\overset{(1)}{CH_3} \quad \text{and} \quad \text{(II) } (\overset{(3)}{CH_3})_3\overset{(4)}{CH}$$

In normal butane (formula I) there are two kinds of hydrogen atoms, when we consider the position of these atoms in the molecule. All six atoms joined to the end carbons are alike and are marked (1). The other hydrogen atoms are like one another but differ in their position from those which are joined to the end carbon atoms. These are marked (2). In isobutane (formula II) the nine hydrogen atoms in the three methyl groups are alike. The atom marked (4) differs from the others in position. It is evident that formulas for hydrocarbons containing five carbon atoms can be written if we replace one hydrogen atom in the butanes by a methyl group. All the possible isomers should be obtained in this way, if the different hydrogen atoms are replaced in turn. The derived formulas are obtained by replacing the hydrogen atoms marked (1), (2), (3), (4), respectively, by methyl.

(1) $CH_3CH_2CH_2CH_2CH_3$

(2) $\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!\overset{*}{C}HCH_2CH_3$

(3) $\begin{matrix} CH_3CH_2 \\ (CH_3)_2 \end{matrix}\!\!>\!\overset{*}{C}H$

(4) $(CH_3)_3CCH_3$

As the formulas are written they appear to represent four distinct arrangements of the atoms. By a careful examination of the ones marked (2) and (3) it will be seen that they are alike. In

each formula there is one carbon atom, marked with an asterisk (*), which is joined to one hydrogen atom, two methyl groups, and one ethyl group. This hydrocarbon can be considered to be a derivative of methane, formed as the result of the replacement of three hydrogen atoms by these groups; it is called dimethyl-ethyl-methane. The hydrocarbon numbered (4) is tetramethyl-methane.

The three pentanes, which are known, can be prepared by methods which indicate that they have the structures represented by the formulas deduced above. Normal pentane and isopentane (dimethyl-ethyl-methane) occur in petroleum. These hydrocarbons are not appreciably affected by acids, bases, or oxidizing agents. They react with chlorine and bromine, and burn in the air. Normal pentane boils at 36°; isopentane at 28°, and tetramethyl-methane at 9.5°. It has been observed as the result of the study of a number of hydrocarbons that isomers have different boiling points, and, in general, the isomer with the longer chain has the higher boiling point. In normal pentane there is a chain of five carbon atoms, in isopentane a chain of four, and in tetramethyl-methane a chain of three.

Higher Members of the Methane Series

28. As the number of carbon atoms in the hydrocarbons increases, the number of isomers which are possible according to the structure theory increases. It has been calculated that there should be five compounds of the formula C_6H_{14}, 9 of the formula C_7H_{16}, 75 of the formula $C_{10}H_{22}$, 802 of the formula $C_{13}H_{28}$, and so on. But few of the compounds which are indicated by the theory are known. Chemists have, however, carried the study of the isomerism among these hydrocarbons far enough to feel convinced that the theory is in accord with the facts. The five hexanes, which have the formula C_6H_{14}, have been prepared. The 9 possible heptanes, 15 of the possible octanes, and a smaller number of isomers of the higher hydrocarbons are known. Certain experimental difficulties are encountered when an attempt is made to synthesize hydrocarbons with the more complex arrangement of atoms.

Many hydrocarbons which have the normal structure are known. Such compounds can be prepared readily, and the fact

that many of them occur in petroleum has led to their study. A table of the composition and the more important physical properties of a number of the normal hydrocarbons of the methane series is here given.

NORMAL HYDROCARBONS, C_nH_{2n+2}

Name	Formula	Melting point, °C.	Boiling point at 760 mm., °C.	Density
Methane	CH_4	−184	−161.4	$0.415^{-164°}$
Ethane	C_2H_6	−172	− 88.3	$0.546^{-88°}$
Propane	C_3H_8	−189.9	− 44.5	$0.585^{\frac{-44.5°}{4°}}$
Butane	C_4H_{10}	−135	0.6	$0.601^{0°}$
Pentane	C_5H_{12}	−131.5	36.2	$0.631^{20°}$
Hexane	C_6H_{14}	− 94.3	69.0	$0.660^{\frac{20°}{4°}}$
Heptane	C_7H_{16}	− 90	98.4	$0.684^{20°}$
Octane	C_8H_{18}	− 56.5	124.6	$0.707^{17°}$
Nonane	C_9H_{20}	− 51	150.6	$0.718^{\frac{20°}{4°}}$
Decane	$C_{10}H_{22}$	− 32	174	$0.747^{\frac{20°}{4°}}$
Undecane	$C_{11}H_{24}$	− 26.5	197	$0.741^{\frac{20°}{4°}}$
Dodecane	$C_{12}H_{26}$	− 12	216	$0.768^{\frac{20°}{4°}}$
Tridecane	$C_{13}H_{28}$	− 6.2	234	$0.757^{\frac{20°}{4°}}$
Tetradecane	$C_{14}H_{30}$	5.5	252.5	$0.765^{\frac{20°}{4°}}$
Pentadecane	$C_{15}H_{32}$	10	270.5	$0.772^{\frac{20°}{4°}}$
Hexadecane	$C_{16}H_{34}$	20	287.5	$0.775^{\frac{20°}{4°}}$
Eicosane	$C_{20}H_{42}$	36.7	$205^{15mm.}$	0.778 (at m.p.)
Dotriacontane	$C_{32}H_{66}$	75	$310^{15mm.}$	0.775 (at m.p.)

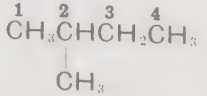
An inspection of the table shows that the hydrocarbons which contain more than four carbon atoms are named from the Greek numerals which signify the number of carbon atoms in the molecule. Each compound differs in composition from the next member in the series by CH_2. This results from the fact that such a series can be built up by replacing one hydrogen atom by a CH_3 radical. Many such series of compounds are known in which the members have similar chemical properties and differ

in composition by CH_2. Such relationship is known as *homology* and the compounds constitute a *homologous* series. Any compound in the series is said to be a *homologue* of any other compound in the series.

While the chemical properties of the members of a homologous series are, in general, the same, an increase in the number of carbon atoms is associated with a gradual change in physical properties. It will be observed from the table that the first four hydrocarbons are gases at the ordinary temperature; from pentane to hexadecane they are liquids, and the compounds which contain more than 16 carbon atoms are solids. An increase in molecular weight corresponding to CH_2 brings about an increase in boiling point, which grows less as the molecular weight of the hydrocarbon increases. Thus, between the boiling points of butane and pentane there is a difference of 35.6°, between hexane and heptane 29.4°, and between hendecane and dodecane 19°. Similar facts are observed in other homologous series.

29. Nomenclature of Paraffin Hydrocarbons.—Two methods of naming compounds of this class are in use. One method is as follows: The hydrocarbon is considered as a compound derived from methane by the replacement of one or more hydrogen atoms by radicals. In selecting the atom which is to be considered as the carbon atom of methane, that atom is chosen which is united with the largest number of carbon atoms. This method is illustrated in the way the pentanes are named (**27**).

In the second method of naming saturated hydrocarbons (*Geneva system*) the longest straight chain of carbon atoms in the compound to be named is taken as the nucleus about which the hydrocarbon is built; the latter is named as a substitution product of the normal paraffin which contains the number of carbon atoms present in the straight chain selected. In order to indicate the position of the side chains the carbon atoms in the straight chain are numbered in such a way that the side chains are in combination with the carbon atoms to which the lowest numbers have been assigned. Thus dimethyl-ethyl-methane is also called 2-methyl-butane:



30. Heat of Combustion and Heat of Formation.—*By the heat of combustion of a compound is meant the amount of heat which is set free when one gram-molecule of the substance is burned to carbon dioxide and water.* The heats of combustion of a few of the methane hydrocarbons are given in the following table. The heat unit used is the large calorie (1,000 small calories).

HEATS OF COMBUSTION OF NORMAL PARAFFINS
In large calories (1,000 small calories)

Name	Heat of combustion	Differences
Methane	210.8	
		157.6
Ethane	368.4	
		157.9
Propane	526.3	
		156.0
Butane	(682.3)	
		156.0
Pentane	838.3	
		152.3
Hexane	990.6	
		159.3
Heptane	1149.9	
		3×153.4
Decane	1610.2	
		6×157.6
Hexadecane	2556	
		4×156.8
Eicosane	3183	

It is seen that the increase in the heat of combustion in the homologous series is nearly constant for an increase of CH_2. An examination of a number of such series brings out the fact that a difference in composition in CH_2 corresponds, on the average, to a difference of 156 Calories in the heat of combustion. It is thus possible to calculate approximately the amount of heat developed when a compound is burned, provided the heat of combustion of a homologue is known.

The heat of formation of a compound is the amount of heat set free when one gram-molecule of the substance is formed from its elements. It is impossible to determine directly the heat of formation of an organic compound, but this quantity can be calculated from the heat of combustion of the elements which make up the compound and the heat of combustion of the compound itself. Thus, the heat of combustion of amorphous carbon (12 grams) is 94.4 Cal., and of hydrogen (1 gram) is 34.2 Cal. The heat which is set free, accordingly, when 12 grams of carbon and 4

grams of hydrogen are burned equals 94.4 Cal. + 4(34.2 Cal.) = 231.2 Cal. The heat of combustion of methane (16 grams) is 210.8 Cal. The difference between these two quantities, 20.4 Cal., is taken as the heat of formation of methane, *i.e.*, the amount of heat which is liberated in the union of carbon and hydrogen to form methane.

The heat of formation of the paraffin hydrocarbons is positive, *i.e.*, heat is given off in their formation. They are *exothermic* compounds. The heats of formation of some hydrocarbons are negative. This means that the compounds when burned produce more heat than is produced when the equivalent weights of carbon and hydrogen are burned. Such compounds are called *endothermic*.

31. Chemical Properties of the Paraffins.—The paraffin hydrocarbons are characterized by their inertness to many chemical reagents. By the long-continued action of nitric acid and of sulphuric acid the higher members of the series, *i.e.*, those containing a large number of carbon atoms, are converted into derivatives which contain nitrogen and sulphur, respectively. For example, when hexane is heated with fuming nitric acid for 40 hours about 10 per cent of the hydrocarbon is converted into nitrohexane, $C_6H_{13}NO_2$. The reaction is represented by the equation

$$C_6H_{14} + HONO_2 = C_6H_{13}NO_2 + H_2O$$

With fuming sulphuric acid under similar conditions sulphonic acids are formed:

$$C_6H_{14} + HOSO_2OH = C_6H_{13}SO_2OH + H_2O$$

The substances formed in this way belong to important classes of compounds which will be discussed later. The nitro and sulphonic acid derivatives of the paraffins are usually made by other reactions.

Chlorine and bromine react with the hydrocarbons and form substitution products. As mixtures of compounds are obtained in this way the reactions are not often used in the preparation of halogen derivatives.

32. Detection of the Paraffins.—The identification of the paraffins is difficult on account of the lack of definite analytical tests. The paraffins are characterized by their inertness. They

can be shaken with fuming nitric acid without appreciable change. They are insoluble in concentrated sulphuric acid and are not attacked by it. The liquid hydrocarbons react slowly with bromine; a solution of the halogen in the hydrocarbon retains its color for some time. As reaction takes place hydrobromic acid is evolved. The hydrocarbons are insoluble in water and float. They dissolve in alcohol and benzene.

The properties which have been stated are those of the pure hydrocarbons. Many commercial mixtures such as gasoline, benzine, kerosene, etc., consist largely of paraffins. Such mixtures when subjected to the tests stated above react to some extent, on account of the fact that they contain small quantities of other more reactive hydrocarbons. When these have entered into reaction the paraffin hydrocarbons which are left exhibit their characteristic inertness.

33. Petroleum.—Petroleum is the most important source of the paraffin hydrocarbons. The oil is widely distributed, and is found in large quantities in America and Russia. The most productive regions in the United States are California, Illinois, Pennsylvania, Texas, Kansas, and Oklahoma.

The nature of the processes by which such large quantities of petroleum and natural gas have been formed in the earth has been the subject of speculation and experiment by geologists and chemists. The oil is found in sandstones of practically all geological ages although the larger part of it occurs in the later formations. Many theories have been put forward as to the way in which it has been produced. According to one of these, hydrocarbons have been formed by the action of water or steam on carbides of metals. Aluminium carbide (**21**) reacts with water to form methane, and the carbide of iron yields liquid hydrocarbons when decomposed. But since most petroleums rotate the plane of polarized light when it is passed through them, that is, are optically active (**81**), it is highly probable that they have not been formed from carbides. The phenomenon of optical activity in nature is associated with substances that have possessed life. Further, petroleum is obtained from geological formations in which remains of animal and vegetable life are present.

Petroleum contains organic compounds of sulphur, and many varieties are rich in nitrogen compounds. As these elements are

constituents of proteins which are present in all living things, the fact is additional evidence in favor of the organic origin of petroleum. Whether or not the oil was formed from animal or vegetable sources is an open question; it is possible that the petroleums in different localities, which differ markedly in composition, may have been derived from different sources. By subjecting the fatty oil from fish to destructive distillation under pressure, Engler obtained a product that resembled closely American petroleum. Many plants are rich in fat and would yield under similar conditions a mixture of hydrocarbons and organic compounds containing sulphur and nitrogen derived from the protein material present. It has been pointed out by Potonié that a probable source of petroleum is the floating vegetable and animal material which develops abundantly in fresh-water ponds. It rapidly dies, is replaced by a fresh growth, sinks to the bottom of the pond, and forms a "putrefying ooze." This material is rich in fats and as it collects rapidly in large quantities could have served as the source of petroleum. It is known that in the first stages of its decomposition it produces marsh gas, CH_4.

Oils resembling petroleum are obtained in Scotland by the destructive distillation of bituminous shale, a kind of rock which is rich in organic matter. When distilled these shales yield ammonia, hydrocarbons, paraffin wax, and phenols (**535**). The American shales are now being studied intensively with the expectation of the development of a new source of petroleum products.

A synthetic petroleum is now being manufactured in Germany by the *Bergius process*, in which powdered coal is heated at about 450° with hydrogen at 300 atmospheres pressure. The gasoline made in this way has proved to be a good motor fuel.

34. Crude petroleum is an oily liquid which varies in color from amber to black. Some varieties are red, brown, or orange, and by reflected light often appear greenish in tint. Most American oils contain paraffin hydrocarbons. The hydrocarbons from methane to the one having the composition $C_{27}H_{56}$ have been isolated from Pennsylvania oils. The California and Texas oils contain appreciable proportions of aromatic hydrocarbons, C_nH_{2n-6}; they are rich in nitrogen bases derived from pyridine and quinoline. The Russian petroleum consists largely of hydrocarbons called naphthenes (**682**), which are isomeric with the hydrocarbons of the ethylene series, but differ from them in chemical properties.

From the standpoint of the refiner, crude petroleum is classified as a "paraffin-base" oil, an "asphalt-base" oil, or one of a mixed type. The former on distillation yields a high-boiling fraction from which paraffin wax crystallizes on cooling; the asphalt-base oils furnish no crystalline hydrocarbons, but heavy greases. The oils from the Appalachian field in the United States are paraffin-base oils; those obtained from California and Texas are asphalt-base oils. Petroleum is measured in barrels which contain 42 gallons.

The crude oil is purified and separated into a number of commercial products by distillation. The first fraction, which is collected up to 210°, is *gasoline;* then follow *kerosene*, 210° to 275°, and *gas oil*, 275° to 300° or higher. The high-boiling oils, which are used for lubrication, are then distilled until a residue of coke is left. In order to lower the temperature of distillation and thus prevent partial decomposition of the hydrocarbons, these oils are usually distilled with dry steam; when reduced pressure is used the so-called "vacuum" oils are produced.

When paraffin-base oils are refined the higher-boiling oils are chilled and *paraffin* crystallizes out. In the case of other oils the residue is petroleum asphalt. *Vaseline* or petrolatum is made from the residuum of oils with high boiling points, which is distilled in a vacuum. The color is removed by filtering the oil through fuller's earth.

In order to purify the oils further, the separate fractions are agitated with concentrated sulphuric acid and are finally washed with water.

35. *Cracking.*—In order to increase the yield of the lighter oils from petroleum, the latter is *cracked, i.e.*, it is heated to such a temperature that a part of the less volatile hydrocarbons is decomposed into gases and saturated and unsaturated hydrocarbons of low molecular weight. In this way the percentage of gasoline obtained is increased. A great many ways of accomplishing this have been invented and a number are in use. In the *Burton process*, petroleum is distilled in a system which is closed so that a pressure of 4 to 5 atmospheres is maintained. The temperature within the still varies from 650° to 850° F. The condenser is so constructed that the vapors of the higher-boiling hydrocarbons are condensed and returned to the still, while the more volatile ones pass on and are condensed later. The pressure in the still makes it possible to heat the liquids to a high temperature and decreases the percentage of gases formed.

In the more modern cracking processes the oil is passed under pressure (150 to 700 lb.) through tubes heated to a high temperature (830° to 850° F.).

36. *Ozokerite*, or earth wax, is widely distributed, but is usually found in small quantities. It consists chiefly of solid paraffin hydrocarbons and varies in color from yellow to black. It is thought to have been formed as the result of the evaporation of crude petroleum. It is purified by melting it with hot water and separating the oil from the earthy material. After treatment with sulphuric acid, water, and caustic soda, it is obtained in an almost colorless condition. The refined material, called *ceresin*, is used as a substitute for beeswax.

Asphalt is a black bituminous material which is supposed to have been formed as the result of the evaporation and partial oxidation of petroleum.

It consists of compounds of carbon and hydrogen, some of which contain in addition oxygen, sulphur, and nitrogen; these are mixed with varying amounts of earthy material. Asphalt melts when heated; on account of its physical properties it serves as an excellent binding material in making surfaces for roads, etc. The chief source of asphalt is Pitch Lake on the Island of Trinidad, which is 135 feet deep at the center and has an area of over 100 acres.

Problems

1. Write equations for the reactions involved in preparing butane in four different ways.

2. Write the graphic formulas of (*a*) the pentanes and (*b*) the hexanes, and name each compound according to the two methods described in Sec. **29.**

3. Write equations for reactions by which the following could be prepared: (*a*) C_5H_{12} from C_4H_{10}; (*b*) C_3H_8 from C_3H_7OH; (*c*) C_2H_6 from CH_3COOH.

4. (*a*) What volume of air must be mixed with propane to furnish just enough oxygen to burn it to carbon dioxide and water? What is the percentage of propane in the mixture (*b*) by volume and (*c*) by weight?

5. When 50 c.c. of a mixture of methane and an excess of air was exploded the volume of the residual gas after the removal of carbon dioxide and water was 38 c.c. (*a*) How many cubic centimeters of methane did the 50 c.c. contain? (*b*) What was the percentage by volume of each component in the mixture? (*c*) What volume of carbon dioxide was formed as the result of the explosion? (*d*) What volume of oxygen was converted into carbon dioxide?

6. Show how a pure gaseous hydrocarbon of the methane series could be identified by exploding a known volume of the gas with a known volume of air and determining the oxygen in the residual gas.

7. Calculate from the formula of butane (*a*) the weight of 1 liter of the gas, (*b*) the specific gravity of the gas compared with hydrogen, and (*c*) with air.

8. Why is kerosene a safer material to handle than gasoline?

9. Is a mixture of gasoline vapor and air lighter or heavier than air? Give a reason for your answer.

10. (*a*) If the average molecular weight of a sample of gasoline containing only paraffin hydrocarbons is 114, what volume of air is required to burn one volume of the vapor of the gasoline to carbon dioxide and water? (*b*) Would such a mixture explode when brought into contact with a flame? (*c*) Why is gasoline a dangerous substance?

11. From the thermochemical equation given in Sec. **22** and the fact that a sample of coal furnished 7,500 calories per gram, calculate (*a*) the volume in liters of methane required to furnish the same amount of heat as 1 gm. of the coal, and (*b*) the volume of the gas in cubic feet (1 cu. ft. = 28.3 l.) equivalent in heat production to 1 ton (1,000 kg.) of the coal.

12. How many gallons (1 gal. = 3.79 l.) of a fuel oil (sp. gr. 0.900), which furnishes 10,300 calories per gram, is equivalent in heat production to 1 ton of coal that furnishes 7,000 calories per gram?

CHAPTER III

HYDROCARBONS OF THE ETHYLENE SERIES
DIOLEFINS

37. Ethylene, C_2H_4, is the first member of the homologous series of hydrocarbons having the composition represented by the general formula C_nH_{2n}. Repeated efforts have failed to prepare a compound of this series with but one carbon atom. The homologues of ethylene contain two fewer hydrogen atoms than the hydrocarbons in the methane series with the same number of carbon atoms. Thus, we have propane, C_3H_8; butane, C_4H_{10}; and hexane, C_6H_{14}; and propylene, C_3H_6; butylene, C_4H_8; hexylene, C_6H_{12}; etc. The hydrocarbons of this series are named, as illustrated, by replacing the ending *ane* in the name of the saturated compound by the termination *ylene*, or by changing the vowel *a* in the termination to *e*. The compound having the formula C_7H_{14} is called heptylene or heptene.

Ethylene was originally called olefiant (meaning oil-forming) gas, on account of the fact that it formed an oil when it reacted with chlorine. For this reason homologues of ethylene are often called *olefins*.

Formation.—Ethylene is frequently formed when non-volatile organic compounds are subjected to destructive distillation, or when hydrocarbons are heated to such a temperature that they undergo decomposition. The ethylene found in coal gas and in carburetted water gas is produced in this way. Natural gas also contains a small percentage of this hydrocarbon. The luminosity of illuminating gas is due in part to the presence of ethylene, which is present in the gas to the extent of from 4 to 5 per cent.

Properties.—Ethylene is a colorless gas which possesses a peculiar, sweetish odor. One volume of water dissolves one-fourth volume of the gas, and one volume of alcohol about three and one-half volumes. It is much less stable toward heat than

methane. At about 600° it decomposes; methane, acetylene, benzene, and other hydrocarbons are formed. Ethylene burns with a brilliant flame. A mixture of the gas and air explodes violently when ignited.

Preparation.—Theoretically, ethylene could be prepared by removing two hydrogen atoms from ethane. As the removal of hydrogen atoms alone from a compound can usually not be effected, the difficulty is overcome by first replacing hydrogen by halogen, and subsequently removing the latter. The halogens have a great affinity for metals, and *when organic compounds which contain two halogen atoms joined to neighboring carbon atoms are treated with metals, the halogen atoms are removed.* A typical reaction is represented by the following equation:

$$C_2H_4Br_2 + Zn = C_2H_4 + ZnBr_2$$

A second method of preparing the hydrocarbon illustrates another principle which is important, as it can be applied to the preparation of many compounds which show the behavior of ethylene. *When an alkyl halide,* ethyl bromide for example, *is heated with an alcoholic solution of potassium hydroxide, the base removes one hydrogen and one halogen atom.* In this way ethylene can be prepared from ethyl bromide:

$$C_2H_5Br + KOH \text{ (in alcohol)} = C_2H_4 + KBr + H_2O$$

If the potassium hydroxide is dissolved in water the halogen atom is replaced by the hydroxyl group, and alcohol is formed.

A third method of preparation is important on account of its general applicability. *It consists in the removal of the elements of water from an alcohol:*

$$C_2H_5OH + \text{a dehydrating agent} = C_2H_4 + H_2O$$

This can be accomplished by passing the vapor of the alcohol through a hot tube. In the presence of a catalyst the temperature at which the reaction takes place is lowered; with aluminium oxide ethylene is formed rapidly at about 350°.

Ethylene can be prepared readily by heating alcohol with an active dehydrating agent. When a mixture of the alcohol and phosphorus pentoxide is heated, a steady evolution of the gas is produced. When sulphuric acid is used the mixture is heated to

about 170° to 180°. The reaction takes place in two stages: When the alcohol and the acid are mixed they react according to the following equation:

$$C_2H_5OH + H_2SO_4 = C_2H_5.HSO_4 + H_2O$$

A compound, acid ethyl sulphate, commonly called ethylsulphuric acid, is formed. This substance subsequently decomposes thus:

$$C_2H_5.HSO_4 = C_2H_4 + H_2SO_4$$

In the *industrial preparation of ethylene* the gas is obtained by cracking natural gas or the lighter liquid hydrocarbons, or as a by-product in the cracking of petroleum.

38. Chemical Reactions of Ethylene.—Ethylene and its homologues are much more reactive than the hydrocarbons of the methane series. This activity is due to the fact that while two carbon atoms have the capacity of holding in combination six univalent atoms as in the case of ethane, in ethylene but four such atoms are present. The compound is, therefore, said to be *unsaturated.* When it is brought in contact with certain elements or compounds, ethylene forms new compounds by adding atoms or groups of atoms. In this process two univalent atoms or groups are added to the hydrocarbon, and a *saturated* compound is formed, *i.e.*, a compound in which the two carbon atoms hold in combination six atoms or groups—the maximum number possible on the assumption that carbon has the valence of four.

The more important *addition reactions* of this type are as follows:

With the Halogens.—When ethylene is passed into bromine, direct combination takes place and ethylene bromide is formed:

$$C_2H_4 + Br_2 = C_2H_4Br_2$$

Addition products are also formed with chlorine and with iodine. The difference in the readiness with which ethylene chloride and ethylene iodide are formed illustrates clearly the difference in the activity of the two halogens. In the case of chlorine the reaction must be carried out in the dark and the temperature must be kept low. Even in diffused light, ethylene burns in chlorine with a smoky flame. The reaction is analogous to

that between methane and chlorine. It takes place essentially according to the equation

$$C_2H_4 + 2Cl_2 = 2C + 4HCl$$

The influence of sunlight on reactions in which the halogens are involved is marked. It will be seen later that the course of many such reactions is determined by this factor. The student will remember that sunlight brings about the union of chlorine and hydrogen.

Ethylene does not react so readily with iodine as with chlorine. When the gas is passed into a warm solution of iodine in alcohol, the two substances unite slowly.

With Hydrogen Halides.—At 100° ethylene reacts with concentrated hydriodic acid, and ethyl iodide is formed:

$$C_2H_4 + HI = C_2H_5I$$

An analogous reaction takes place less readily with hydrobromic acid, but with hydrochloric acid no compound is formed. The difference in reactivity of the halogens and halogen acids, as shown in their behavior with ethylene, is in general characteristic of these substances. Chlorine is the most active halogen and hydriodic acid is the most active acid.

With Sulphuric Acid.—Ethylene is absorbed slowly by concentrated sulphuric acid, and ethylsulphuric acid is formed:

$$C_2H_4 + H_2SO_4 = C_2H_5.HSO_4$$

It will be remembered that at about 170° ethylsulphuric acid undergoes decomposition into ethylene and sulphuric acid.

With Hypochlorous Acid.—Ethylene reacts in the cold with a dilute solution of hypochlorous acid, and ethylene chlorohydrin, which is a chlorine substitution product of ethyl alcohol, is formed:

$$C_2H_4 + HOCl = CH_2Cl.CH_2OH$$

The reaction can be brought about by passing a mixture of ethylene and carbon dioxide into a suspension of bleaching powder in water; the carbonic acid formed liberates hypochlorous acid from the calcium hypochlorite produced from the bleaching powder. The reaction was utilized in the preparation of "mustard gas" (**414**). When ethylene and chlorine are passed into

water a similar reaction takes place. The chlorine reacts with water and forms hydrochloric and hypochlorous acids, $Cl_2 + HOH = HCl + HOCl$; and the ethylene unites with the latter. In a similar way ethylene bromohydrin, $CH_2Br.CH_2OH$, is formed when ethylene is passed into dilute bromine water.

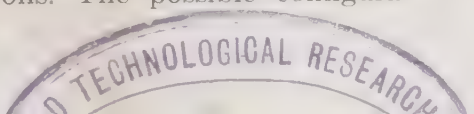
With Hydrogen.—When a mixture of ethylene and hydrogen is passed over finely divided nickel at about 300° the hydrocarbon is reduced to ethane; carbon and methane are also formed as the result of the decomposition of a part of the ethylene. After the reaction has started the temperature can be reduced to 0°; under these conditions the transformation is nearly quantitative. The reaction between ethylene and hydrogen is exothermic, and the mixture of the gases must be cooled to prevent overheating when addition takes place.

With Oxidizing Agents.—Whereas the paraffin hydrocarbons resist to a high degree the action of oxidizing agents, ethylene and its homologues are oxidized readily. Aqueous solutions of chromic acid oxidize ethylene to carbon dioxide. Neutral or alkaline solutions of potassium permanganate form, along with other substances, glycol, $\begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix}$, the reaction bringing about the addition of two hydroxyl groups to ethylene.

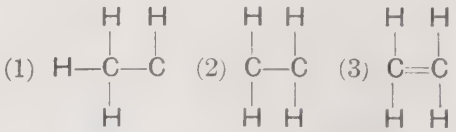
Uses of Ethylene.—When ethylene burns in oxygen a very hot flame is produced. On this account ethylene can be used to replace acetylene for welding purposes. The gas can be stored under high pressure without danger of explosion, and as a consequence a much smaller tank could be used than in the case of acetylene.

Ethylene is used in the manufacture of ethyl alcohol (**68**) and ethylene glycol and its derivatives (**93**), some of which are important drugs.

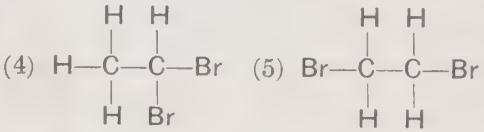
39. Structure of Ethylene.—The property possessed by ethylene of forming compounds by direct addition with other substances is observed in the case of many other organic compounds. In writing graphic formulas of such unsaturated compounds, an attempt is made to represent the structure of molecules which should be capable of such reactions. The possible configura-



tions of a molecule of ethylene may be represented by these formulas:

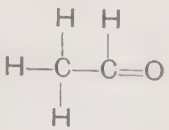


In formula (1) one of the carbon atoms is represented as having the valence 2. Since the maximum valence of carbon is 4, the unsaturation of ethylene must lie on this one carbon atom if this formula is correct, and the formula of the bromide formed from ethylene and bromide must be that of formula (4) below:



In the case of a compound having the structure represented by either formula (2) or (3) the bromide formed from it would have the structure represented by formula (5); for in the former case both carbon atoms are represented with the valence 3, and in the latter the fourth bond of each carbon atom is represented by a second line between the two, which serves to indicate that two of the affinities of each atom are concerned in their union.

It is possible to decide between formula (1) on one hand and formulas (2) and (3) on the other from a consideration of the methods of formation of the two dibromoethanes. One of these compounds is formed when acetaldehyde is treated with phosphorus pentabromide. The structure of acetaldehyde has been shown by methods independent of this reaction to be represented by the following formula:



In the conversion of acetaldehyde into dibromoethane the simplest interpretation of the reaction leads to the view that the oxygen which it contains is replaced by two of the bromine atoms of the pentabromide, which is thereby converted into phosphorus oxybromide, $POBr_3$: its structure is, accordingly, that repre-

sented in formula (4) above. The dibromoethane formed in this way is not the one which results from the addition of bromine to ethylene; this latter compound must, as a result, have the structure represented by formula (5) above, since formulas (4) and (5) represent all the possible configurations of a compound of the composition $C_2H_4Br_2$. These facts exclude the possibility that ethylene has the structure represented by formula (1).

To decide between formulas (2) and (3) is more difficult. If bromine atoms add to molecules having the structures represented by these formulas, the same dibromide, formula (5), would be obtained. In formula (2) the carbon atoms are represented with the valence 3; in formula (3) they are given the valence 4, it being assumed that they are held together as the result of the utilization of two valency forces on each atom. To represent this latter kind of union two lines are placed between the atoms so combined; they are said to be joined by a *double bond.* Unsuccessful attempts were made for many years to prepare a compound in which the presence of a trivalent carbon atom could be definitely shown. For this and other reasons the formula of ethylene and other unsaturated compounds of this type has been represented as containing two doubly linked carbon atoms. In recent years compounds which contain a trivalent carbon atom have been prepared (**451**) but their chemical behavior is such that it has not changed the conception of the way in which the carbon atoms in ethylene are held together.

40. Propylene, C_3H_6.—The hydrocarbon of this series which contains three carbon atoms is called propylene. It may be considered as derived from ethylene by the replacement of one hydrogen atom by a methyl group. As the four hydrogen atoms in ethylene are alike, there is no opportunity for isomerism. The structural formula of propylene is $CH_3.CH{=}CH_2$. The compound is a gas. It can be prepared by methods which are analogous to those used to prepare ethylene. For its preparation propylene bromide, $C_3H_6Br_2$, propyl iodide, C_3H_7I, or propyl alcohol, C_3H_7OH, may be used. It will be remembered that two isomeric monosubstitution products of propane are possible. For example, two iodides are known: normal propyl iodide, $CH_3CH_2CH_2I$, and isopropyl iodide, $CH_3.CHI.CH_3$. The fact that both compounds yield propylene when heated with an

alcoholic solution of potassium hydroxide shows that in the formation of the unsaturated hydrocarbon the hydrogen and iodine atoms which are removed are joined to adjacent carbon atoms in the propyl iodides. A study of a large number of substances has shown that *when unsaturation is established by removing two atoms or groups from a saturated compound, the carbon atoms which become unsaturated as the result of such removal are joined to each other.*

Propylene formed as a by-product in the cracking of petroleum is used in the manufacture of isopropyl alcohol (**77**).

41. Butylenes, C_4H_8.—Three butylenes are possible according to the structure theory and three are known. The formulas may be written by replacing a hydrogen atom in propylene by a methyl group. Propylene has the formula $CH_3.CH=CH_2$. It is evident that the hydrogen atoms joined to each of the carbon atoms bear different relations to the molecule. The formulas for the possible butylenes are as follows:

(1) $CH_3CH_2CH=CH_2$

(2) $\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!C=CH_2$

(3) $CH_3CH=CHCH_3$

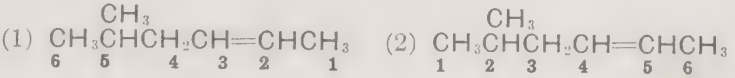
The three compounds are known. The one to which the first formula is assigned is called normal butylene; the second is isobutylene. In order to make clear the structure of hydrocarbons in this series they are often named as derivatives of ethylene. The butylene which has the structure represented by formula (2) is called unsymmetrical dimethylethylene, and that represented by formula (3), symmetrical dimethylethylene.

The methods of preparing these hydrocarbons, and their reactions, are in accord with the three formulas which have been assigned to them. They resemble ethylene in the ability to form compounds by direct addition with the halogens, halogen acids, sulphuric acid, etc.

They readily undergo *polymerization* when treated with strong sulphuric acid or with zinc chloride; *i.e.*, two or more molecules of butylene form new compounds by addition to each other. From butylene, C_4H_8, can be prepared in this way dibutylene, C_8H_{16}, which is an octylene, and tributylene, $C_{12}H_{24}$, which is a

dodecylene. This polymerization is, no doubt, due to the unsaturation produced by the double bond, although the reaction is not shown by ethylene.

42. Nomenclature of Olefin Hydrocarbons.—The compounds are named by replacing the termination *ane* in the paraffin hydrocarbon containing the same number of carbon atoms by the ending *ylene* or *ene*. In order to indicate the position of the double bond and of substituents the carbon atoms are numbered from one end in such a way that the smallest numbers possible are assigned to (1) the unsaturated atoms (method of *Chemical Abstracts*) or (2) the side chains (*Geneva System* and *Beilstein*). Thus,



is according to (1) 5-methyl-2-hexene and to (2) 2-methyl-hexene-4.

Higher Members of the Ethylene Series

43. Homologues of Ethylene.—Five isomeric pentenes have been prepared. These hydrocarbons, which contain five carbon atoms, are called amylenes as they can be prepared from the amyl alcohols, $C_5H_{11}OH$. The following table gives a list of some of the members of this series. The boiling points given are those of the normal hydrocarbons.

Normal Hydrocarbons of the Ethylene Series, C_nH_{2n}

Name	Formula	Melting point, °C.	Boiling point at 760 mm., °C.	Density
Ethylene	C_2H_4	−169.4	−103.8	$0.566^{\frac{-102°}{4°}}$
Propylene	C_3H_6	−185.2	− 47	$0.609^{\frac{-47°}{4°}}$
Butene-1	C_4H_8	−130	− 18	$0.668^{0°}$
Pentene-1	C_5H_{10}	.....	30.0	$0.641^{\frac{20°}{4°}}$
Hexene-1	C_6H_{12}	− 98.5	64	$0.683^{\frac{20°}{4°}}$
Heptene-1	C_7H_{14}	.....	92°–93°	$0.700^{19°}$
Octene-1	C_8H_{16}	.....	123	$0.722^{17°}$
Hexadecene-1	$C_{16}H_{32}$	4	274	$0.789^{\frac{20°}{4°}}$

These hydrocarbons can be prepared by the methods described when ethylene was considered. In their chemical reactions they also resemble the typical member of the series. In the addition of such substances as hydriodic acid and sulphuric acid to the unsymmetrical hydrocarbons, *i.e.*, those which have different arrangements of atoms on either side of the double bond, there is opportunity for the formation of isomeric compounds. Thus, when hydriodic acid and propylene unite, it is possible that the addition may take place in two ways. In one case the addition of the iodine atom to the central carbon atom and of hydrogen to the end carbon atom would yield isopropyl iodide, $CH_3.CHI.CH_3$. If the iodine were to add to the end of the chain propyl iodide, $CH_3.CH_2.CH_2I$, would result. Propylene and hydriodic acid form but one addition product and this is isopropyl iodide. In a number of cases, addition takes place in a similar manner, *i.e.*, the acid radical, I, SO_4H, etc., joins itself to the carbon atom to which is united the smaller number of hydrogen atoms. In general, the negative atom or group unites with the carbon atom which is joined to the largest number of carbon atoms. When, however, there is no marked difference between the carbon atoms, the two possible isomeric compounds are formed; under these circumstances the concentration of the reacting substances and the temperature determine the relative proportions of the isomers formed.

44. Identification of Hydrocarbons of the Ethylene Series.—The most characteristic reactions of substances containing the double bond are, perhaps, the addition of bromine and the reducing action on a solution of potassium permanganate and sodium carbonate, a reagent suggested for this purpose by Baeyer. There are substances more highly unsaturated than ethylene, and others which do not contain a double bond, which react with these reagents in the way in which compounds containing a double bond react. If these are excluded by proper tests—and we shall see later how this is to be done in most cases—a positive test of an unknown substance with bromine and with potassium permanganate is a strong indication of the presence in it of a double bond.

The test with bromine is carried out by treating a solution of the compound in carbon tetrachloride, CCl_4, or some other

solvent which is not affected by the halogen, with a solution of bromine in the solvent used to dissolve the substance under examination. A reaction is indicated by the disappearance of the color produced by the bromine. If this does not take place in a few minutes the solution should be gently heated. In the case of a double-bonded compound the reaction takes place as the result of addition and no hydrobromic acid is formed. If this gas is produced it is evident that substitution has taken place, and the test fails to give any evidence as to the presence of an unsaturated compound. The presence of hydrobromic acid can be shown by blowing one's breath across the mouth of the tube in which the test is made; if the acid is present it will fume with the moisture in the breath.

The second test is applied by shaking the compound with a dilute, cold solution of potassium permanganate and sodium carbonate. If an unsaturated compound is present oxidation takes place, the color of the solution disappears, and brown manganese dioxide is formed.

The tests which have been described are used to detect unsaturated compounds. It is difficult to prove that a compound under study is a hydrocarbon. To do this a qualitative test for elements other than carbon, hydrogen, and oxygen must be made. If such elements are shown to be absent, the substance must be tested for the characteristic groups which contain oxygen. These tests will be developed in the pages to follow. If all such tests yield negative results the conclusion can be drawn that the substance studied belongs to the class of unsaturated hydrocarbons.

45. Heat of Combustion and Heat of Formation of the Hydrocarbons of the Ethylene Series.—The significance of the heat of combustion and heat of formation of the members of the ethylene series can best be seen by comparing the values of the constants of these hydrocarbons with those of the paraffins. The heat of formation of ethane is 25.6 large calories. This means that when 24 grams of carbon and 6 grams of hydrogen unite to form ethane, 25.6 large calories of heat are evolved—the reaction is exothermic—and, consequently, ethane contains less chemical energy than the carbon and hydrogen from which it was formed. On the other hand, ethylene is an endothermic com-

pound. In order to transform 24 grams of carbon and 4 grams of hydrogen into ethylene, the energy equivalent to 6.4 large calories is necessary. This means that ethylene contains more chemical energy than the elements from which it was formed.

HEAT OF COMBUSTION AND HEAT OF FORMATION OF PARAFFINS AND OLEFINS IN LARGE CALORIES

Name	Formula	Heat of combustion	Heat of formation
Methane	CH_4	210.8	20.4
Ethane	C_2H_6	368.4	25.6
Ethylene	C_2H_4	332.0	− 6.4
Propane	C_3H_8	526.3	30.5
Propylene	C_3H_6	490.2	− 1.8
Isobutane	$(CH_3)_2CH.CH_3$	683.4	36.2
Isobutylene	$(CH_3)_2C{=}CH_2$	647.2	− 3.0
Isopentane	$(CH_3)_2CH.CH_2CH_3$	843.2	39.2
Isopentylene	$(CH_3)_2CH.CH{=}CH_2$	803.6	−10.4

46. Thermochemical Equations in Organic Chemistry.—It is impossible to determine directly the heat evolved or absorbed in reactions between organic molecules, except in a very few cases. The values can be readily calculated, however, from the heats of combustion of the substances involved in such reactions. The thermal effects that accompany chemical changes are helpful in interpreting the behavior of molecules. This fact will be illustrated by a number of cases later.

To calculate the heat effect of a reaction the molecular equation of the reaction is first written and the heats of combustion of the substances are indicated. For example,

$$\underset{332}{C_2H_4} + \underset{68.4}{H_2} = \underset{368.4}{C_2H_6}$$

One mole (28 grams) of ethylene yields 332 large calories when it is burned; likewise 1 mole (2 grams) of hydrogen yields 68.4 large calories, and 1 mole (30 grams) of ethane, 368.4 large calories. The total heat generated by burning the substances shown on the left side of the equation is, accordingly, 332 + 68.4 = 400.4 Calories. The product when burned yields 368.4 Calories. The difference between these two numbers, 400.4 − 368.4 = 32, is the number of large calories liberated

when the reaction indicated by the equation takes place. Since more heat is obtained by burning ethylene and hydrogen than by burning ethane the difference is positive and the reaction is exothermic.

This method of calculation is based on a law of thermochemistry which states that the total heat absorbed or evolved in passing from one system to another is independent of the number of steps in the process, provided the final products are identical. In the case illustrated we can either convert ethylene and hydrogen directly into carbon dioxide and water by burning, or we can cause them to unite first and form ethane and then burn the latter. In both ways the same amount of heat is produced. If the union is first effected heat must be evolved in this step, because the ethane produced does not yield as much heat, when burned, as do the ethylene and hydrogen from which it is formed. The thermochemical equation for the reaction is accordingly written as follows:

$$C_2H_4 + H_2 = C_2H_6 + 32 \text{ Cal.}$$

When 2 grams of hydrogen unite with oxygen, and water is formed, the heat evolved is equal to 68.4 Calories. When the same weight of hydrogen unites with ethylene nearly one-half this amount of heat is produced. The reaction is thus a very energetic one.

Diolefins

47. A number of hydrocarbons are known which contain four less hydrogen atoms than the saturated hydrocarbon with the same number of carbon atoms. A study of the reactions of these hydrocarbons has shown that the property of unsaturation which they possess is produced as the result of the presence of two double bonds. *Allene* has the structure represented by the formula $H_2C{=}C{=}CH_2$. The hydrocarbons of this series are called *diolefins* on account of the fact that they contain two double bonds. Allene is sometimes called propadiene. The first two syllables indicate that the compound contains three carbon atoms (from propane C_3H_8); the termination *diene* indicates the presence of two double bonds in the compound. Other compounds are named in a similar way. The methods of preparation and

reactions of the members of this series are analogous to those of the hydrocarbons of the ethylene series.

48. Isoprene, C_5H_8, is a diolefin of particular interest on account of the fact that it is partly converted into rubber when it is heated under pressure. The hydrocarbon is a liquid which boils at 34°. It is formed as the result of the destructive distillation of rubber, or when turpentine is passed through a red-hot tube. The reactions of the substance indicate that it has the structure

$$CH_2{=}C(CH_3){-}CH{=}CH_2$$

It is, consequently, 2-methyl-butadiene-1,3. Like other olefins it can be readily polymerized. When isoprene undergoes this change there are formed liquid hydrocarbons called terpenes, on account of their relation to turpentine, and a substance which appears to be identical with rubber.

49. The synthesis of rubber on a commercial scale has been the subject of much investigation. The chief difficulty has been to prepare isoprene from a substance that can be obtained in large quantities at a low cost. Turpentine yields but a small percentage of isoprene when heated and cannot serve, therefore, as the source of the hydrocarbon.

The study of hydrocarbons related to isoprene has brought out the fact that butadiene itself, $CH_2{=}CH.CH{=}CH_2$, and certain of its derivatives undergo a polymerization that yields products which resemble rubber closely in properties. One of these products was made in Germany on a large scale during the World War and was used in the manufacture of automobile tires and other products needed in warfare. This synthetic rubber was made from a dimethylbutadiene of the structure $CH_2{=}C(CH_3){-}C(CH_3){=}CH_2$ which was readily prepared from acetone (**198**), a substance that can be obtained in large quantities. The hydrocarbon was converted into a methyl derivative of ordinary rubber by keeping it in a sealed vessel at 60° for about two months.

50. Natural rubber is obtained from the juice present in various trees and shrubs which grow best in tropical countries. On account of the commercial importance of rubber the trees which yield it are grown systematically on plantations; formerly the supply was obtained from natural forests. The intensive cultivation of rubber trees has had a marked effect in lowering the price and insuring a steady supply of rubber. For this reason the synthesis of rubber is, at present, of little economic significance.

When isoprene and similar hydrocarbons polymerize all of the double bonds present are not involved in the union of the several molecules; the rubber formed as a result is unsaturated. It shows the reactions characteristic of the derivatives of ethylene. Owing to this unsaturation it will add sulphur. This process, which is called vulcanization, was discovered by Goodyear in 1839. Vulcanization is usually effected by heating the mixture of rubber and sulphur at about 140°. Sheet rubber can be vulcanized in the cold by dipping it into a dilute solution of sulphur monochloride in a volatile solvent, such as carbon disulphide or benzene.

The properties of the vulcanized product vary with the amount of sulphur used. In the preparation of rubber for most purposes from 5 to 7 per cent of the weight of the rubber is used. In making ebonite, or hard rubber, up to 30 per cent is employed. It is probable that in vulcanization a part of the sulphur unites chemically with the rubber and a part is held by physical adsorption. The exact nature of the process is not yet understood.

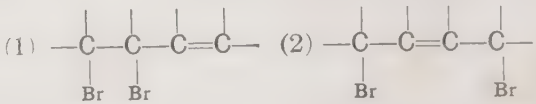
In the preparation of most rubber articles so-called "fillers" are used. These serve to add body to the product and to increase the tensile strength of the rubber and the ability to resist abrasion. They also decrease the time required for vulcanization. Among the substances commonly used are zinc oxide, barium sulphate, gypsum, whiting, magnesium carbonate, silica, etc. Gas black, which is obtained as the result of the incomplete combustion of natural gas, is employed in making the rubber used in certain types of automobile tires. For some unknown reason it is superior for this purpose to ordinary lampblack.

Certain organic substances have a marked effect on the rate at which vulcanization takes place. The "accelerators" that have been used are compounds containing nitrogen more or less closely related to ammonia; among these are aniline, piperidine, para-phenylenediamine, and thiocarbanilide. The use of accelerators has made it possible to increase the output of a tire factory more than three times.

It has been shown that certain so-called negative catalysts retard the oxidation of rubber, which results in brittleness and loss of elasticity. Such anti-oxidants are now used extensively.

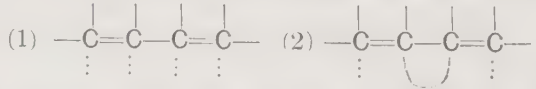
51. Conjugated Double Bonds.—Isoprene and many other compounds have the configuration represented by the symbols $-\overset{|}{C}=\overset{|}{C}-\overset{|}{C}=\overset{|}{C}-$, *i.e.*, they have two singly linked carbon atoms both of which are joined by a double bond to the next atom in the chain. Many of these compounds show an anomalous behavior when they unite by direct addition with the halogens or other elements. If only two atoms of bromine are added to such a compound we would expect that one double bond would be broken and the other would remain intact, and the compound

formed would have the structure represented by formula (1) below:

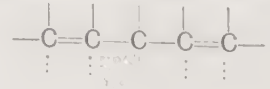


The compound formed has, however, the structure indicated by formula (2). In order to distinguish between the two methods of addition, that represented by the first formula is called 1,2 addition, and the latter 1,4 addition. The numbers are arrived at by numbering the carbon atom involved from 1 to 4. When two double bonds in a compound are situated as indicated above they are said to be *conjugated.* In such a chain we have carbon atoms linked by a double bond, then a single bond, and then a double bond.

In order to explain 1,4 addition, Thiele suggested the hypothesis of partial valence, which has been valuable in interpreting the results obtained when addition takes place to a system of conjugated double bonds. He put forward the view that since all the energy of two carbon atoms is not expended when they are united by double bonds, each atom possesses a certain amount of residual affinity. This conception is represented by formula (1):



A dotted line drawn from the symbol of a carbon atom serves to indicate that the atom possesses what is called a partial valence. When a compound contains a conjugated system of double bonds there are two adjacent carbon atoms—numbers 2 and 3 in the chain—that exhibit partial valence. Under these circumstances these residual affinities neutralize each other and the state of unsaturation of these atoms disappears. This result is indicated in formula (2) above. The result of this is that when addition takes place atoms 1 and 4 are involved, because they are the ones which possess free partial valences. If the double bonds are not conjugated such neutralization of the partial valences cannot take place. This is evident from a consideration of the chain of carbon atoms indicated by the following symbols:



It does not contain two adjacent singly linked carbon atoms which possess partial valences. Addition to such carbon atoms is normal. Certain compounds which contain a conjugated system of double bonds do not exhibit 1,4 addition, but in the case of many of these an adequate explanation has been furnished.

Problems

1. Using propylene as an example, write equations for reactions (*a*) by which olefins can be prepared, and (*b*) to illustrate the chemical behavior of olefins.

2. Write graphic formulas of the hydrocarbons of the composition C_5H_{10} and name each according to the two methods given in Sec. **42.**

3. Write the graphic formulas of the compounds formed as the result of the addition of hydrobromic acid to the following: (*a*) isopropylethylene; (*b*) butene-1; (*c*) 3-methyl-pentene-2; (*d*) 2,4-dimethyl-pentene-1.

4. How could you determine the percentage by volume of the constituents in the following mixtures: (*a*) air and ethylene; (*b*) air and methane; (*c*) propylene and propane; (*d*) butane, air, and ethylene?

5. Certain anti-knock gasolines contain unsaturated hydrocarbons. How could you distinguish these from a gasoline obtained in the distillation of a Pennsylvania petroleum?

6. (*a*) How many cubic centimeters of a solution of bromine in carbon tetrachloride, which contains 0.05 gm. of bromine per cubic centimeter, will be decolorized by 0.5 gm. of hexene? (*b*) One gram of a mixture of hexane and hexene decolorized 5 c.c. of the bromine solution. What was the percentage of the hexane in the mixture?

7. Calculate the heat evolved when (*a*) hydrogen adds to propylene and forms propane, and (*b*) when hydrogen adds to isobutylene and forms isobutane. (*c*) Compare the results with the heat evolved when ethane is formed from ethylene.

CHAPTER IV

HYDROCARBONS OF THE ACETYLENE SERIES

52. A homologous series of hydrocarbons is known the members of which show a higher state of unsaturation than that of the olefins. Acetylene, the most important member of the series, has the composition indicated by the formula C_2H_2. It contains two fewer hydrogen atoms than ethylene. We have seen in the study of the relation between ethylene and ethane that the removal of hydrogen atoms from compounds leads to the formation of substances which are active chemically. This activity, called unsaturation, shows itself in the ability of such substances to form new compounds as the result of direct addition to other elements. The relation between the composition of ethylene and acetylene, C_2H_4 and C_2H_2, is an indication that acetylene is more highly unsaturated than ethylene—*i.e.*, that it possesses the ability to add more atoms than does ethylene. The facts are in accord with this conclusion. Whereas one molecule of ethylene unites with two atoms of bromine, one of acetylene can unite with four atoms of the halogen. In both cases a saturated compound is formed, which is a substitution product of ethane, C_2H_6.

The hydrocarbons of this series should be studied in the light of their relation to the olefins. The methods of preparation are analogous to those explained when ethylene was considered, but the extent of the elimination of halogen atoms or of hydrogen halide must be increased; four halogen atoms or two molecules of the halide must be removed. The reactions of acetylene and its homologues are, in general, analogous to those of ethylene.

The graphic formula of acetyiene which is used to represent the structure of its molecule and to indicate that it is capable of adding to itself four univalent atoms is $HC \equiv CH$. In such addition, two of the three bonds which are represented as holding the carbon atoms together are said to break. This leaves one

bond between the carbon atoms. The two latent affinities of each of these atoms come into play and, as a consequence, four atoms are added to the molecule.

53. Acetylene, C_2H_2.—This hydrocarbon is the most important in the series on account of the fact that it illustrates in its reactions the chemical conduct of its homologues, and because it has been applied to a number of important uses.

Physical Properties.—Acetylene is a gas which has a garlic-like odor. Under a pressure of 48 atmospheres at 1° it condenses to a colorless liquid which boils at −83.6° and has the density 0.613 at its boiling point. Acetylene is slightly soluble in most liquids; one volume of water, benzene, and alcohol dissolve one, four, and six volumes, respectively, of the hydrocarbon. One volume of acetone dissolves at the ordinary temperature and pressure 25 volumes, and at a pressure of 12 atmospheres 300 volumes, of acetylene.

Uses.—Acetylene cannot be stored under pressure without the risk of explosion. As a consequence, a solution in acetone is used. Tanks to hold acetylene are filled with a highly porous material, such as asbestos, to which acetone is added. Acetylene is then forced in until the liquid is saturated at a pressure of 10 atmospheres. Acetylene stored in this way is used in connection with oxygen in the acetylene torch to produce a flame at a very high temperature, which is used in cutting and welding steel and other metals. When welding is to be done the supply of oxygen is cut down so that it can be accomplished in a reducing atmosphere. With the proper amount of oxygen the following reaction takes place:

$$C_2H_2 + O_2 = 2CO + H_2$$

The carbon monoxide and hydrogen formed burn on the extreme edge of the flame. If a metal is to be cut an excess of oxygen is used and the supply of acetylene is shut off after the proper temperature has been reached. The hot metal burns in the stream of oxygen, and as the torch is slowly moved a narrow cut is made.

An important application of acetylene is its use as an illuminant. On account of the ease of its preparation from calcium carbide and water, acetylene is used extensively as an illuminant by small towns which cannot afford the cost of the installa-

tion and operation of a gas plant. The high illuminating power of an acetylene flame is due to the fact that the gas contains a high percentage of carbon and that when it burns the large amount of heat produced raises the temperature of the flame to a high point. The temperature of the flame is said to be about 2350°.

Acetylene is used in the manufacture of a number of organic compounds of industrial importance (**109, 184**).

Formation.—Acetylene is formed when hydrogen is heated with carbon at the temperature of the electric arc and when most hydrocarbons are decomposed at a high temperature. It is also formed when certain complex organic substances are subjected to destructive distillation at a high temperature. Coal gas contains about 0.08 per cent of acetylene, which is formed in this way. Incomplete combustion of hydrocarbons and other organic compounds leads to the formation of the gas. Acetylene is formed in small quantity when a Bunsen burner strikes back and the gas burns at the base in a supply of air which is not sufficient for complete combustion. The odor of the gases formed is not that of pure acetylene but of other substances present.

Preparation.—Acetylene is most conveniently prepared by the action of water on calcium carbide. When lime and coal are heated in an electric furnace the oxide is reduced, and at the high temperature the metal unites with carbon and calcium carbide results. The reaction takes place according to the following equation:

$$CaO + 3C = CaC_2 + CO$$

Calcium carbide is a hard, white, crystalline substance when pure; the brown color of the commercial material is due to the presence of iron and other impurities. A steady stream of acetylene can be produced by allowing water to fall, drop by drop, on the carbide. The equation for the reaction is

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2.$$

In some forms of generators for the gas, which are used commercially, the finely powdered carbide runs slowly into a reservoir of water. A better regulation of the gas supply is effected by using this method, and overheating, which may lead to an explosion, is avoided. Acetylene prepared from commercial calcium

carbide contains ammonia, hydrogen sulphide, and phosphine. These substances must be removed when the gas is to be used for indoor illumination. The purification is effected by washing the gas with water and a mixture of slaked lime and bleaching powder, or with a solution of chromic acid in hydrochloric acid. In the laboratory a solution of mercuric chloride in dilute hydrochloric acid can be conveniently used for the purpose.

54. Acetylene can be prepared by other methods which are analogous to those used to prepare ethylene. While these methods lack practical value in the case of this hydrocarbon, which can be so readily prepared from calcium carbide, they are of importance since similar methods must be used to prepare the homologues of acetylene. Moreover, compounds other than hydrocarbons may contain carbon atoms held together in the way in which these atoms are united in acetylene, and the methods about to be described can be used to prepare such compounds.

The most important general method of preparing a compound containing a triple bond is to heat with an alcoholic solution of potassium hydroxide a saturated halogen derivative which contains two halogen atoms joined to either the same or adjacent carbon atoms.

Acetylene may be prepared in this way from ethylene bromide.

$$BrH_2C—CH_2Br + 2KOH = HC{\equiv}CH + 2KBr + 2H_2O$$

The removal of four halogen atoms from a saturated compound by means of a metal also leads to the establishment of a triple bond. When an alcoholic solution of symmetrical tetrabromoethane is warmed with zinc, acetylene is formed:

$$Br_2HC—CHBr_2 + 2Zn = HC{\equiv}CH + 2ZnBr_2$$

55. Chemical Reactions of Acetylene.—Acetylene and other substances which contain two carbon atoms joined by a triple bond, show in their chemical behavior a high state of unsaturation.

With Halogens.—Acetylene does not react with chlorine in the dark, but in diffused daylight addition of the halogen takes place and a dichloride, $C_2H_2Cl_2$, and a tetrachloride, $C_2H_2Cl_4$, are formed. If the acetylene has not been carefully purified, the reaction often takes place with explosive violence and carbon and

hydrogen chloride are formed. When the gas is passed into bromine the chief product of the reaction is acetylene tetrabromide:

$$HC{\equiv}CH + 2Br_2 = Br_2HC{-}CHBr_2$$

Acetylene reacts with iodine which has been covered with alcohol and forms a diiodide, $C_2H_2I_2$.

With Hydrogen Halides.—Acetylene does not appear to unite directly with hydrochloric acid; with concentrated hydrobromic acid at 100° a reaction takes place slowly, and one molecule of the hydrocarbon and one of the halogen acid unite and form bromoethylene, $H_2C{=}CHBr$. Under similar conditions with hydriodic acid, iodoethylene, $H_2C{=}CHI$, and ethylidene iodide, CH_3CHI_2, are formed.

With Hydrogen.—Acetylene and hydrogen unite in the presence of finely divided platinum and form ethane and ethylene.

With Oxidizing Agents.—Acetylene, like other unsaturated compounds, is readily oxidized by a solution of potassium permanganate. Oxalic acid, carbon dioxide, and other substances are formed as the result of the oxidation.

With Water.—When acetylene is passed into a solution of mercuric sulphate and sulphuric acid it unites with water and is converted into acetaldehyde (**184**):

$$HC{\equiv}CH + H_2O = H_3C.CHO$$

With Oxygen.—Acetylene decomposes with explosive violence when heated to about 780°. Mixtures of acetylene and air explode at about 480°. The proportion of acetylene in such mixtures can vary between wide limits, namely, from 3 to 82 per cent by volume. In the case of methane and ethylene, the limiting volumes of explosive mixtures are 5 and 13 per cent and 4 and 22 per cent, respectively.

Polymerization.—Acetylene polymerizes when it is passed through a tube heated to dull redness. Among the compounds formed is benzene, C_6H_6, which is produced as the result of the union of three molecules of the unsaturated hydrocarbon.

With Cuprous Chloride.—The reactions of acetylene which have been mentioned are analogous to those of the unsaturated hydrocarbons containing a double bond. Acetylene and other compounds which contain a carbon atom in combination with

hydrogen and joined to a second atom in the manner which is represented by a triple bond, *i.e.*, those containing the group H—C≡, show characteristic properties which serve to distinguish them from other substances. Such compounds are converted into metallic derivatives when they are treated with an ammoniacal solution of cuprous chloride or of silver chloride. If acetylene is passed into a solution of cuprous chloride in ammonia, a red precipitate is formed which has the composition C_2Cu_2. This compound, which is a carbide of copper, is usually called copper acetylide. It explodes, when dry, if it is struck or is heated to 100° to 120°. When treated with hydrochloric acid or with a solution of potassium cyanide, acetylene is formed.

With Sodium.—Acetylene and other compounds which contain the ≡CH group react with sodium and potassium and form metallic derivatives. When acetylene is passed over gently heated sodium, one-half of the hydrogen in the hydrocarbon is replaced by the metal and a sodium acetylide, C_2HNa, is formed. At red heat the disubstituted product C_2Na_2 results.

56. Structure of Acetylene.—The structural formula of acetylene is deduced from its reactions. Arguments similar to those used in the case of ethylene and propylene lead to the conclusion that the state of unsaturation is brought about as the result of the relation existing between the two carbon atoms in the hydrocarbon. The formula is written, accordingly, HC≡CH. The fact that acetylene is formed when iodoform, CHI_3, is treated with zinc is an argument in favor of the accepted structure of the hydrocarbon. The properties of certain substitution products of acetylene have led to the view that derivatives of a hydrocarbon isomeric with acetylene and having the structure $H_2C{=}C$ may exist.

Thermochemistry of Acetylene.—A study of the heat of combustion of acetylene throws some light on the nature of the union of the carbon atoms in the compound and on its chemical activity and instability. When one gram-molecule of acetylene (26 grams) burns in oxygen, 312 Calories are set free. The heat produced when the same amount of carbon (24 grams) and hydrogen (2 grams) in the free state are burned is 257.2 Calories. Acetylene is, accordingly, an endothermic compound; its heat of formation is −54.8 Calories. This storing up of energy in the molecule

leads to the instability and reactivity which is characteristic of acetylene and similar compounds. Acetylene cannot be safely stored when under a pressure greater than two atmospheres, or when liquefied. Under these conditions the substance may explode as the result of a shock.

The thermochemical equations for the union of acetylene with hydrogen and with water are as follows:

$$CH{\equiv}CH + 2H_2 = C_2H_6 + 80.4 \text{ Cal.}$$

$$CH{\equiv}CH + H_2O = CH_3CHO + 31.5 \text{ Cal.}$$

Higher Members of the Acetylene Series

57. A number of hydrocarbons of this series, the general formula of which is C_nH_{2n-2}, have been prepared by the application of the general methods of synthesizing compounds containing carbon atoms joined by a triple bond. In general, these hydrocarbons resemble acetylene in chemical properties. Only those, however, which contain the $\equiv CH$ group, form metallic compounds. Methylacetylene (propine), $CH_3C{\equiv}CH$, which is usually called allylene, is a gas; ethylacetylene (butine), $CH_3CH_2C{\equiv}CH$, boils at 18°. As is the case in other homologous series, increase in the number of carbon atoms is accompanied by an increase in boiling point. The higher members of the series are solids.

58. Nomenclature.—The hydrocarbons in this series are usually named as substitution products of acetylene; for example, methylacetylene, dimethylacetylene, etc. Some of the hydrocarbons have, in addition, names which were given them when they were first prepared. Methylacetylene is often called, for example, allylene.

In the Geneva system of nomenclature the name of any hydrocarbon is derived from that of the saturated hydrocarbon which contains the same number of carbon atoms by replacing the termination *ane* by *ine* or *yne;* thus, acetylene, C_2H_2, is called ethine; and methylacetylene, $CH_3C{\equiv}CH$, propine. To indicate the position of the triple bond the carbon atoms in the longest straight chain containing the triple bond are numbered in the manner used in the case of the olefins.

59. Identification of Compounds Containing a Triple Bond. The unsaturated character of compounds which contain carbon atoms joined by a triple bond is shown by their behavior with bromine and with a solution of potassium permanganate. Tests for such compounds are carried out in the manner described under ethylene (**44**). Acetylene derivatives can be readily distinguished from compounds containing doubly linked carbon atoms, only when the former contain the group $\equiv CH$. In the case of such substances an insoluble, colored copper derivative is formed when the compound is treated with an ammoniacal solution of cuprous chloride. There is no simple qualitative test which serves to distinguish a compound of the structure $RC\equiv CR$ (R is used to represent a radical) from one of the structure $R_2C=CR_2$.

Problems

1. (*a*) Write equations for reactions by which methylacetylene can be prepared in two different ways. Write equations for the reactions that take place when methylacetylene is treated with (*b*) an ammoniacal solution of cuprous chloride, (*c*) bromine, (*d*) hydrobromic acid, (*e*) hydrogen.

2. State how you could distinguish from one another (*a*) acetylene, ethylene, and ethane; (*b*) dimethylacetylene and ethylacetylene; and (*c*) isoprene, methylacetylene, and butene.

3. Starting with acetylene how could the compound $CH_2Br.CHBr_2$ be prepared?

4. Through the use of inorganic reagents how could you determine the percentage composition by volume of a mixture composed of acetylene, ethylene, and ethane?

5. Can you give an explanation of the fact that the explosive limits of acetylene, methane, and ethylene (**55**) are so different?

6. (*a*) Calculate the heat evolved in the following reactions:

$$C_2H_2 + H_2 = C_2H_4 + x \text{ Cal.}$$
$$C_2H_2 + 2H_2 = C_2H_6 + y \text{ Cal.}$$
$$C_2H_4 + H_2 = C_2H_6 + z \text{ Cal.}$$

Heats of combustion, H_2 68.4, C_2H_2 312, C_2H_4 332, C_2H_6 368.4 Cal. (*b*) Compare the values of x and y and z in relation to the unsaturation in the two hydrocarbons.

CHAPTER V

SATURATED ALCOHOLS CONTAINING ONE HYDROXYL GROUP

60. The derivatives of the hydrocarbons which contain oxygen are of the greatest importance, as most organic compounds that occur in nature contain this element. A study of many of these compounds has shown that they can be brought into a comparatively small number of groups, the members of which show similar chemical properties. The substances known as alcohols constitute one of these groups. The chemical properties of these compounds lead to the conclusion that they are hydroxyl derivatives of the hydrocarbons. Alcohols are known which contain more than one hydroxyl group. Those containing one such group are sometimes called monohydroxy alcohols. The polyhydroxy alcohols are classified as dihydroxy, trihydroxy, etc.

61. Methyl Alcohol, CH_3OH.—Compounds occur in certain plants from which methyl alcohol can be easily obtained in small quantities. When methyl salicylate (oil of wintergreen), which is present in checkerberries, is heated with a solution of sodium hydroxide, methyl alcohol and the sodium salt of salicylic acid are obtained.

Preparation from Wood.—Methyl alcohol is formed, along with other substances, when wood is subjected to destructive distillation. This method is used in the industrial preparation of methyl alcohol, which is commercially known as wood spirit.

The process is carried out by heating wood out of contact with air in retorts which are so arranged that the volatile products formed can be condensed. When wood is heated decomposition begins at about 160°. Between this temperature and 275° a watery distillate, called *pyroligneous acid*, is formed. As the temperature is increased methane, ethane, ethylene, carbon monoxide, and carbon dioxide are given off along with liquid and solid hydrocarbons. At about 450° the decomposition is complete and a residue of charcoal remains. The yield of the products of distillation is affected by the kind of wood used. The product from birch, beech, and

oak trees produces the largest amount of pyroligneous acid—about 30 per cent of the weight of the wood. The crude acid contains from 1 to 2 per cent of methyl alcohol, 10 per cent acetic acid, 0.5 per cent acetone, and water, together with a number of other substances which are present in small amounts.

Methyl alcohol is obtained by first neutralizing the crude acid with milk of lime, which forms calcium acetate with the acetic acid present, and then submitting the liquid to fractional distillation. A second distillation from quicklime yields an alcohol of 99 per cent. The alcohol so obtained contains acetone and other substances in small quantities, from which it cannot be separated by distillation, and which impart to it an unpleasant odor.

62. Preparation from Carbon Monoxide and Hydrogen.—Under the proper conditions carbon monoxide and hydrogen unite and form methyl alcohol:

$$CO + 2H_2 = CH_3OH + 33.7 \text{ Cal.}$$

The successful application of this reaction to the preparation of methyl alcohol, which is also called *methanol*, has been one of the greatest triumphs of modern industrial organic chemistry. Synthetic methanol is replacing wood alcohol, as it can be made at a price to compete with the latter and is obtained free from the impurities that are present in the alcohol made from wood and are removed with great difficulty.

The success of the process was the result of extensive research and the application of accumulated knowledge in regard to reversible reactions. The addition of hydrogen to carbon monoxide resembles in many ways the addition of hydrogen to nitrogen:

$$N_2 + 3H_2 = 2NH_3 + 24.4 \text{ Cal.}$$

Both reactions are reversible and exothermic. The methods developed in the case of the industrial synthesis of ammonia[1] were applied with certain modifications to the manufacture of methanol. Since the reaction is a reversible one, the percentage of carbon monoxide and hydrogen converted into methanol is dependent on the temperature; and as it is exothermic the yield of the alcohol increases with decrease in temperature. When combination takes place three molecules are changed into one, and, consequently, the conversion takes place to a greater extent under increased pressure. In order to bring about the transformation at as low a temperature as possible a catalyst is used. It has been stated that the optimum conditions for

[1] Norris, "Textbook of Inorganic Chemistry for Colleges," p. 304, McGraw-Hill Book Company, Inc., New York.

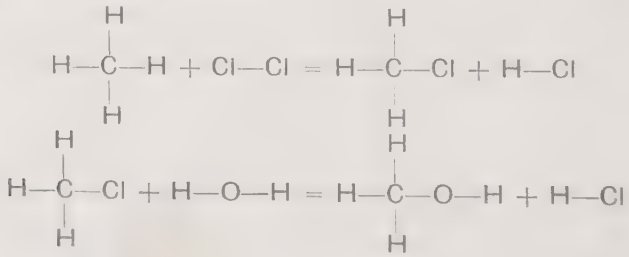
carrying out the reaction on an industrial scale are at a temperature near 400° and at a pressure between 200 and 300 atmospheres. The catalysts used are said to be mixtures of chromium and zinc compounds. It has been found that when certain catalysts are used other alcohols in addition to methanol are produced.

63. *Uses.*—Methyl alcohol is used commercially as a solvent for shellac, in making varnish, in the preparation of aniline dyes and formaldehyde, and for other purposes. Crude wood spirit is used in the preparation of "denatured" alcohol. This use is based on the fact that the crude spirit has a disagreeable odor and is poisonous and, accordingly, renders the grain alcohol unfit to drink.

Properties.—Pure methyl alcohol is poisonous. It differs from ordinary grain alcohol in that it is not completely oxidized in the body to carbon dioxide and water, which are eliminated. It is converted largely into formic acid. In comparatively small doses it produces blindness. Repeated exposure to the vapor of the alcohol mixed with air produces the same result.

Methyl alcohol is a colorless liquid which boils at 64.5° and freezes at −97.8°. It mixes with water in all proportions and is a good solvent. Many substances which are soluble in water and insoluble in most organic liquids dissolve in methyl alcohol. It burns with a pale blue flame, which does not deposit soot, and can be conveniently used as a source of heat.

64. *Synthesis of Methyl Alcohol.*—Methyl alcohol can be prepared from methane by a method that leads to a definite conception of its structure. When the hydrocarbon is treated with chlorine, methyl chloride is formed. This is converted into methyl alcohol by the action of water at a high temperature. The simplest explanation of the reactions is that indicated by the following equations:



The replacement of a halogen atom in a compound by a hydroxyl group is an important method of preparing alcohols. As iodides react with water more readily and at a lower temperature than chlorides, they are more frequently used. In order to increase the rate at which the alcohol is formed the alkyl iodide is shaken or heated with water and silver oxide. It is probable that a reaction takes place between the iodide and the silver hydroxide which is formed from the oxide and passes into solution. The equation is as follows:

$$CH_3I + AgOH = CH_3.OH + AgI$$

The slowness with which the reaction proceeds is in marked contrast with the instantaneous precipitation of silver iodide in a reaction between substances that are ionized to a high degree.

65. Chemical Reactions of Methyl Alcohol.—Methyl alcohol reacts with a number of different kinds of compounds on account of the fact that it contains a hydroxyl group. The more important reactions of the substance will be described at some length, as similar reactions are shown by other alcohols and are typical.

Methyl alcohol may be considered as a compound formed by the replacement of a hydrogen atom in methane by a hydroxyl group, or as water in which one hydrogen atom is replaced by the methyl radical. A consideration of the substance from these points of view will be helpful in understanding and remembering the reactions to be described.

With Salts.—Methyl alcohol reacts with many substances with which water reacts. It forms molecular compounds with certain anhydrous salts which are analogous to hydrated salts. For example, the following compounds are known: $MgCl_2.6CH_3OH$ and $MgCl_2.6H_2O$; $CuSO_4.2CH_3OH$ and $CuSO_4.5H_2O$.

With Sodium.—Sodium and potassium readily replace a part of the hydrogen in both water and methyl alcohol. The reactions in the two cases are analogous:

$$2HOH + 2Na = 2HONa + H_2$$

$$2CH_3OH + 2Na = 2CH_3ONa + H_2$$

In the reaction with the alcohol but one-fourth of the hydrogen —that in the hydroxyl group—is replaced. The reaction takes place when sodium is put into the cold alcohol. Heat is liberated and hydrogen is rapidly evolved. The substance formed is called sodium methylate or sodium methoxide. It is a white solid which is decomposed by water according to the equation

$$CH_3ONa + HOH = CH_3OH + NaOH.$$

It is a reactive substance and is used in the preparation of many compounds.

With Halides of Phosphorus.—It will be remembered that water decomposes the halogen compounds of acid-forming elements. For example, phosphorus trichloride and water react according to the equation

$$PCl_3 + 3HOH = P(OH)_3 + 3HCl.$$

Methyl alcohol shows its relation to water by entering into an analogous reaction:

$$PCl_3 + 3CH_3OH = P(OH)_3 + 3CH_3Cl$$

This reaction, which takes place readily, serves as a convenient means of preparing the alkyl chlorides. Methyl alcohol is converted into methyl bromide and methyl iodide by the bromide and iodide of phosphorus.

With Acyl Chlorides.—There is a class of organic compounds known as acyl chlorides, which react readily with alcohols. The compounds formed are of interest and value, and as the reaction is often used to test substances for the presence of an alcoholic hydroxyl group, it is of importance. An acyl chloride is formed from an acid by the replacement by chlorine of the hydroxyl group which it contains. Phosphorus trichloride, PCl_3, is the chloride of phosphorous acid, $P(OH)_3$; and sulphuryl chloride, SO_2Cl_2, is the chloride of sulphuric acid, $SO_2(OH)_2$. The formula of acetic acid has already been given as $CH_3—\overset{O}{\overset{\|}{C}}—OH$.

Acetyle chloride has the formula $CH_3—\overset{O}{\overset{\|}{C}}—Cl$. Acetyl chloride reacts with water and forms acetic acid and hydrochloric acid,

and with methyl alcohol to form methyl acetate and hydrochloric acid. The equations for the reactions are as follows:

$$CH_3{-}\overset{\overset{O}{\|}}{C}{-}Cl + HOH = CH_3{-}\overset{\overset{O}{\|}}{C}{-}OH + HCl$$

$$CH_3{-}\overset{\overset{O}{\|}}{C}{-}Cl + HOCH_3 = CH_3{-}\overset{\overset{O}{\|}}{C}{-}OCH_3 + HCl$$

When acetyl chloride is added to methyl alcohol the temperature rises and a copious evolution of hydrogen chloride takes place. Other alcohols show a similar reaction.

Basic and Acidic Properties of Methyl Alcohol.—The replacement of a hydrogen atom in water by a methyl radical results in the formation of a compound which shows some of the properties of a base and of an acid. Methyl alcohol gives a very low concentration of hydrogen ions—less than that of water. Methyl alcohol reacts with acids and forms water and substances which show some resemblance to salts. These compounds are known as ethereal salts or esters. The alcohols are, however, neutral to litmus, as they are not appreciably ionized.

Reactions with Hydrogen Halides.—Methyl alcohol reacts with hydrochloric acid when the two are heated in a sealed tube. The reaction takes place according to the equation

$$CH_3OH + HCl = CH_3Cl + H_2O.$$

This reaction does not take place when the alcohol and the concentrated hydrochloric acid are mixed, or even distilled together. In the presence of zinc chloride, which serves as a catalytic agent, a reaction takes place according to the equation given above when the mixture is heated to the boiling point. Methyl alcohol does react, however, with strong aqueous solutions of hydrobromic acid and hydriodic acid. Methyl bromide and methyl iodide may be conveniently prepared by distilling a mixture of the alcohol and a concentrated solution of the halogen acid. In order to convert a large proportion of the alcohol into bromide or iodide, it is necessary to have present an excess of the halogen acid:

$$CH_3OH + HI = CH_3I + H_2O$$

The fact that methyl alcohol is much more readily converted into methyl iodide by hydriodic acid than into methyl chloride

by hydrochloric acid is evidence that the reactions involved are probably not of the same nature as those of neutralization in inorganic chemistry. It is probable that the reaction between the alcohol and the halogen acid involves the formation of an intermediate addition product, which subsequently decomposes into water and the alkyl halide. That such addition products can exist is shown by the fact that when methyl alcohol is treated with liquid hydrobromic acid, a compound having the composition $CH_3OH.HBr$ is formed.

With Sulphuric and Nitric Acids.—When methyl alcohol is warmed with concentrated sulphuric acid, acid methyl sulphate, usually called methyl sulphuric acid, is formed:

$$CH_3OH + H_2SO_4 = CH_3.H.SO_4 + H_2O$$

If the alcohol is distilled with the acid, dimethyl sulphate, $(CH_3)_2SO_4$, results. Methyl nitrate can also be prepared by distilling the alcohol with nitric acid.

With Organic Acids.—Methyl alcohol reacts slowly with organic acids. When equal molecular quantities of the alcohol and an acid are mixed complete reaction does not take place, as the compound formed is decomposed by water, the reaction being reversible. For example, methyl alcohol and acetic acid form methyl acetate and water:

$$CH_3.COOH + CH_3OH = CH_3.COOCH_3 + H_2O$$

When the two substances are heated in a sealed tube at 150° to 155° in order to increase the rate of reaction, 56 per cent of the alcohol and acid are converted into methyl acetate. The significance of this fact will be discussed more fully later (**166**). In order to complete the reaction it is necessary to add to the mixture a dehydrating agent. When sulphuric acid is used reaction takes place when the substances are gently heated. Compounds formed in this way, as the result of the elimination of water from an acid and an alcohol, are called *esters.*

With Oxidizing Agents.—Alcohols differ from hydrocarbons in the ease with which they are oxidized. When an aqueous solution of methyl alcohol is warmed with an oxidizing agent, such as potassium permanganate or chromic acid, oxidation takes place. The final products are carbon dioxide and water. By

careful regulation of the process oxidation products intermediate between the alcohol and carbon dioxide may be obtained. When a red-hot spiral of copper wire which has been superficially oxidized is put into a dilute solution of methyl alcohol in water, a part of the alcohol is oxidized to formaldehyde, $H—\overset{\overset{O}{\|}}{C}—H$. This compound (**182**) has a marked odor and enters with other substances into a number of characteristic reactions which serve as a means of detecting its presence. These reactions will be described when the aldehyde is considered. The formation of formaldehyde in this way is used as a *test for methyl alcohol.*

66. Structure of Methyl Alcohol.—A study of the reactions of methyl alcohol which have been described, leads to the conclusion that the compound contains a hydroxyl group. Its preparation from methyl chloride by the action of water leads to the same conclusion, and furnishes evidence that the substance contains a methyl group. Further, the structure arrived at, which is expressed by the graphic formula

$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & — & C & — & O — H \\ & & | & & \\ & & H & & \end{array}$$

is the only one possible if we accept the view that the valences of carbon, oxygen, and hydrogen are 4, 2, and 1, respectively. This view of the structure is in accord with the fact that one hydrogen atom differs from the other three in its relation to the molecule. It will be remembered that but one-fourth of the hydrogen in methyl alcohol can be replaced by sodium.

67. Ethyl Alcohol, C_2H_5OH.—This substance, which is often called grain alcohol or alcohol, has been known from the earliest times, as it occurs in wine formed as the result of fermentation of grape juice. It is present in the fruit and juices of certain living plants. Alcohol is made in large quantities, not only in the preparation of alcoholic beverages, but for industrial purposes, as it has extensive applications in the arts. Alcohol is formed as the result of the fermentation of sugars. In addition to the sugar which is present in sugar cane and in beets,

substances are found in fruits and vegetables which are sweet, and which readily undergo fermentation. These are called sugars. One of these is dextrose and has the formula $C_6H_{12}O_6$. On account of the fact that this sugar occurs abundantly in grapes, it is often called grape sugar. The formation of wine from grape juice is the result of the fermentation of the dextrose which the juice contains. In the technical preparation of alcohol either starch is first converted into a sugar, called maltose, which is then fermented; or molasses, which contains sugars, is used.

68. In the United States alcohol for industrial purposes is largely made by fermentation from molasses. Smaller quantities are obtained in the preparation of certain beverages, made by fermentation, from which most of the alcohol has been removed before they are sold. Alcohol is also obtained as a by-product in the preparation of yeast, and is now manufactured from ethylene by absorbing the gas in sulphuric acid and hydrolyzing the ethylsulphuric acid formed (**38, 165**). Alcohol rendered unfit to drink by the addition of crude wood alcohol, benzene, or other substances, prescribed by law, is called *denatured alcohol*. It is exempt from taxation.

In the preparation of alcoholic beverages the sugar fermented is usually maltose, which is formed from starch as the result of the action of malt. Malt is usually prepared by allowing barley, softened by water, to sprout in a warm moist atmosphere. During the germination of the grain, diastase is formed; the latter converts starch into maltose. The change which takes place when maltose is converted into alcohol is essentially that represented by the following equation:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_6O + 4CO_2$$

When dextrose is used the equation for the reaction is as follows:

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$$

As the result of the fermentation there is obtained a mixture which contains water, alcohol, fusel oil, acids, yeast cells, and other substances. The alcohol, which is present to the extent of from 10 to 13 per cent, is separated by distillation. Very efficient rectifying apparatus is used in distilling the dilute solution of alcohol. After two distillations alcohol containing but 4 per cent of water is obtained. A mixture of alcohol and water which contains 96 per cent of alcohol by weight cannot be separated into its constituents by distillation, as a mixture of this composition has a constant-boiling point below that of pure alcohol. Toward the end of the distillation there is obtained what is called fusel oil, which consists of two isomeric amyl alcohols, $C_5H_{11}OH$, together with small quantities of other alcohols.

Alcohol has been manufactured recently from sawdust (cellulose) by converting it into dextrose (**366**) and subjecting the latter to fermentation.

69. Absolute alcohol is the name given to alcohol from which all water has been removed. This cannot be done by simple distillation because when a mixture of the two substances is heated to boiling the first part of the distillate is the so-called constant-boiling mixture which contains 95.57 per cent of alcohol by weight, the rest being water. This mixture boils at 78.15°, which is 0.22° below the boiling point of pure alcohol. In order to remove the water, alcohol is treated with some substance which forms a stable compound with water and does not react with alcohol. Quicklime is generally used for this purpose.

In the *industrial preparation of absolute alcohol* a certain amount of benzene is added to 95 per cent alcohol and the mixture is distilled. The part that passes over first is a ternary mixture of alcohol, water, and benzene, which boils at 64.9°. When all the water has been removed in this way, a binary mixture of alcohol and benzene (b.p. 68.3°) distills over; and, finally, absolute alcohol is obtained. The presence of water in alcohol can be detected by adding to it anhydrous copper sulphate; if the salt turns blue, water is present. Barium oxide dissolves in alcohol free from water and imparts to it a yellow color; if water is present the oxide does not dissolve.

Physical Properties.—Pure alcohol is a colorless, mobile liquid which has a characteristic odor. It boils at 78.5°, solidifies at −117.3°, and has the specific gravity of 0.78506 at $\frac{25°}{4°}$. It is miscible in all proportions with water, the mixing being accompanied with contraction and rise in temperature. The greatest contraction takes place when 48 volumes of water and 52 volumes of alcohol are mixed. The volume of the mixture when measured at 20° is 96.3 instead of 100. Alcohol can be obtained readily from a moderately dilute aqueous solution by saturating the solution with potassium carbonate. The alcohol which separates contains about 9 per cent of water.

70. Analysis of Alcoholic Beverages.—The amount of alcohol in a solution is determined as follows: A mixture of 200 c.c. of the sample and 100 c.c. of water is distilled until 200 c.c. has been collected. From the specific gravity and temperature of the distillate the percentage of alcohol can be ascertained by reference to tables in which the specific gravities of aqueous solutions of alcohol are tabulated.

Alcoholic beverages contain many substances in small quantities which affect markedly their quality and value. There are present in wines, for example, in addition to alcohol, acids which are volatile with steam, acids which are not volatile, glycerin, tannin, sugars, esters, solids which are converted into an ash when ignited, etc. The quantitative determination of such substances is often valuable in helping to decide upon the genuineness and value of a wine. The details of these processes and the interpretation of the results are considered in books on the analysis of foods.

71. Uses of Ethyl Alcohol.—Ethyl alcohol is used in pharmacy as a solvent in the preparation of tinctures, essences, and extracts, and in the manufacture of iodoform, chloroform, ether, chloral, and other compounds. It is used to preserve biological specimens, as alcohol coagulates albumen and arrests the growth of the organisms which bring about putrefaction. Alcohol is used in large quantities as a solvent in varnish making, and in other industries in which shellac is used, *e.g.*, the manufacture of felt hats. It is also used in the manufacture of dyes, vinegar, perfumery, collodion, and many other things of commercial value.

Alcohol burns with a blue, smokeless flame, which is a convenient source of heat. Its use for heating purposes has increased since the sale of denatured alcohol was authorized. The so-called "solid" alcohol which is used as a source of heat is a gel made by dissolving soap, calcium acetate, or other substances in hot alcohol; on cooling the small amount of added material sets to a jelly.

The vapor of alcohol mixed with air forms an explosive mixture. In Europe alcohol is used successfully in gas engines to replace gasoline.

72. Chemical Reactions of Ethyl Alcohol.—Ethyl alcohol resembles markedly methyl alcohol in its chemical behavior. It forms compounds with inorganic salts, such as those of the composition $CaCl_2.4C_2H_5OH$, and $PtCl_4.2C_2H_5OH$. It reacts in the cold with sodium and potassium, forming compounds in which the hydrogen in the hydroxyl group is replaced by the metal:

$$2C_2H_5OH + 2Na = 2C_2H_5ONa + H_2$$

A compound of sodium ethylate and alcohol, $C_2H_5ONa.2C_2H_5OH$, crystallizes from alcohol which has been treated with sodium and then cooled. Sodium ethylate, free from alcohol, is obtained by heating this compound to 180°. Sodium ethylate is decomposed by water according to the equation

$$C_2H_5ONa + H_2O = C_2H_5OH + NaOH.$$

The reaction is a reversible one, as it has been shown that a solution of sodium hydroxide in alcohol reacts as if some sodium ethylate were present.

Alcohol reacts with strong inorganic acids. When warmed with concentrated sulphuric acid, ethyl sulphuric acid is formed:

$$C_2H_5OH + H_2SO_4 = C_2H_5.SO_4H + H_2O$$

If alcohol is heated to 160° to 180° with concentrated sulphuric acid, the ethylsulphuric acid first formed is decomposed and ethylene is produced. It will be remembered that the unsaturated hydrocarbons of the ethylene series can be prepared in a similar way from other alcohols.

Ethyl bromide can be prepared conveniently by distilling a mixture of alcohol and an aqueous hydrobromic acid solution which is saturated at its boiling point. Ethyl iodide can be prepared in a similar manner. Alcohol is not converted into ethyl chloride when it is heated with concentrated hydrochloric acid in an open vessel. The reaction takes place, however, if zinc chloride or calcium chloride is present in the mixture in appreciable quantities.

Alcohol reacts with organic acids and forms ethereal salts (esters), the reaction being facilitated by the presence of a dehydrating agent. For example, alcohol and acetic acid, when warmed together in the presence of sulphuric acid, form ethyl acetate:

$$CH_3COOH + C_2H_5OH = CH_3COOC_2H_5 + H_2O$$

The hydroxyl group in alcohol can be replaced by a halogen atom by means of the halides of phosphorus. A reaction between alcohol and phosphorus trichloride takes place according to the following equation:

$$3C_2H_5OH + PCl_3 = 3C_2H_5Cl + P(OH)_3$$

Alcohol reacts with the chlorides of organic acids and forms ethereal salts or esters. For example, alcohol reacts with the

chloride of acetic acid (acetyl chloride) at room temperature, and ethyl acetate is formed:

$$CH_3COCl + C_2H_5OH = CH_3COOC_2H_5 + HCl$$

Alcohol is also converted into esters by acid anhydrides. Acetic anhydride and alcohol form ethyl acetate:

$$(CH_3CO)_2O + C_2H_5OH = CH_3COOC_2H_5 + CH_3COOH$$

The relation between an acid and its ester, chloride, and anhydride is shown by the following formulas:

$CH_3CO.OH$	$CH_3CO.OC_2H_5$	$CH_3CO.Cl$	$(CH_3CO)_2O$
Acid	Ethyl ester	Acid chloride	Acid anhydride

73. *Test for Ethyl Alcohol.*—Ethyl alcohol is best identified by means of its boiling point and that of the bromide, iodide, or benzoate prepared from it. A convenient test for alcohol which is often used is made by adding to a warm aqueous solution of the substance a solution of sodium carbonate and iodine; iodoform, CHI_3, precipitates as a yellow powder and can be recognized by its characteristic odor. The reactions involved will be described later (**274**). The formation of iodoform is not a positive proof of the presence of ethyl alcohol as other substances are converted into iodoform under the conditions used in the test.[1]

74. Principles of Oxidation Applied to Alcohol.—The oxidation of alcohol can be readily effected. The final products are carbon dioxide and water. By varying the conditions under which oxidation takes place, intermediate products of importance can be obtained. These reactions will be considered in some detail, as they illustrate the manner in which conclusions as to the structure of an organic compound are reached by the determination of the products formed when it is oxidized.

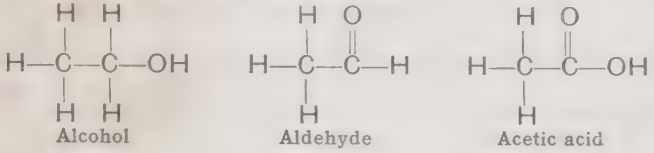
The first product of the oxidation of alcohol is aldehyde, which has the formula C_2H_4O. Aldehyde is converted by oxidizing agents into acetic acid. The composition of these substances is represented by the formulas

C_2H_6O	C_2H_4O	$C_2H_4O_2$.
Alcohol	Aldehyde	Acetic acid

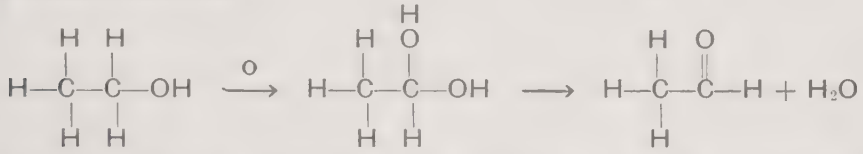
The first step in the oxidation involves the removal of two hydrogen atoms; the second, the addition of one oxygen atom to the alde-

[1] Among these are aldehyde, acetone, propyl alcohol, butyl alcohol, and propionic aldehyde.

hyde formed as the result of the first oxidation. A study of the chemical behavior of alcohol, aldehyde, and acetic acid leads to the conclusion that the structures of these substances are best represented by the following formulas:



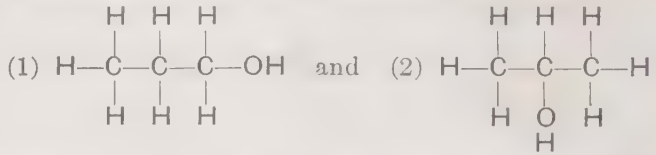
The simplest explanation of the change of alcohol into aldehyde is based on the assumption that one hydrogen atom is oxidized to a hydroxyl group, and that the resulting compound by the loss of water passes into aldehyde. The changes are illustrated by these formulas:



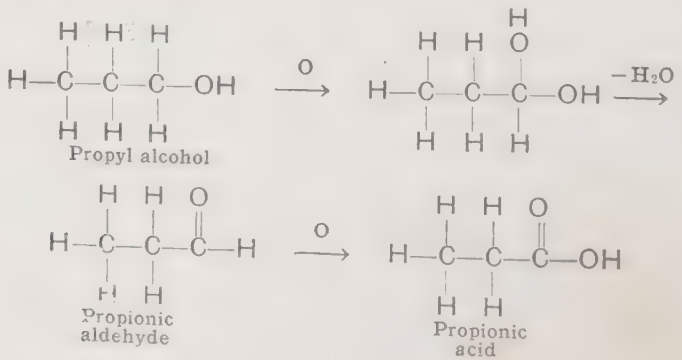
A substance which contains the grouping of atoms represented by the graphic symbol $-C(=O)-H$ is called an aldehyde. The conversion of aldehyde into acetic acid consists in the oxidation of a hydrogen atom to a hydroxyl group. This explanation of the course of the oxidation has been arrived at as the result of the study of the action of oxygen on many compounds. The oxidation of alcohol to aldehyde and acetic acid illustrates three important principles. First, when a compound which contains oxygen is oxidized further, the hydrogen atoms first affected are those joined to the carbon atom that is already in combination with oxygen. Second, the first step in the oxidation is to convert a hydrogen atom into a hydroxyl group; and, third, compounds which contain two hydroxyl groups linked to the same carbon atom are in general unstable, and spontaneously form a new substance by the elimination of water.

These principles are of such importance and wide application that they should be mastered and applied to all cases of oxidation as they are described in the sequel. Like other general principles in organic chemistry they are based on the experimental study of the reactions of many substances.

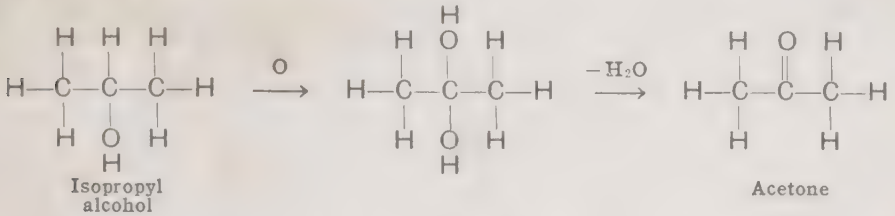
75. Propyl Alcohols, C_3H_7OH.—Two alcohols are known which have the formula C_3H_7OH. According to the structure theory, two monohydroxyl derivatives of propane are possible. These are represented by the following formulas:



The properties of the two propyl alcohols lead to the conclusion that their structures should be represented by these formulas. Both compounds react with sodium, acids, halides of phosphorus, acyl chlorides, and acid anhydrides in the way which is characteristic of alcohols. A study of the products formed as the result of the oxidation of the two alcohols serves to determine the structure that should be assigned to each. The propyl alcohol which boils at 97.8° is converted by oxidizing agents into an aldehyde and an acid. It resembles ethyl alcohol in this respect. The isomeric alcohol boils at 82.3° and does not yield an aldehyde on oxidation. Acetone, a substance which belongs to the class of compounds known as ketones, is first formed. On further oxidation acetic acid is produced. These reactions can be interpreted by the application of the principles underlying the process of oxidation, which have already been given. Such an interpretation illustrates how a study of the products formed as the result of oxidation assists in the determination of the structure of organic compounds. The oxidation of the alcohol, the structure of which is represented by formula (1), above, should take place, according to the principles of oxidation, as follows:



The application of the same principles to the isomeric alcohol, formula (2), should yield different results:



It follows, therefore, that the alcohol which yields an aldehyde on oxidation must have the structure represented by formula (1), and the isomeric alcohol, which gives acetone, must have that represented by formula (2). The difference between the action of oxidizing agents on the two alcohols is due to the fact that one alcohol contains the group $-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-OH$ and the other the group $-\overset{\overset{H}{|}}{\underset{|}{C}}-OH$. In the first case two stages in the oxidation process are possible; in the second but one is possible before further oxidation leads to deep-seated decomposition of the compound in which the carbon atoms are separated. All alcohols that contain the group $-CH_2OH$ joined to *one* radical are called *primary alcohols;* they yield on oxidation an aldehyde and an acid containing the same number of carbon atoms as the alcohol from which it is formed.

Alcohols which contain the group $=CHOH$ joined to *two* radicals are called *secondary alcohols;* they are converted by oxidizing agents into ketones which have the general formula $\begin{matrix}R\\R'\end{matrix}>C=O$, where R and R′ represent the same or different alkyl radicals. On further oxidation the ketone is converted into acids which contain a smaller number of carbon atoms than the alcohol.

Alcohols which contain *three* alkyl radicals linked to the same carbon atom are called *tertiary alcohols.* The butyl alcohol which has the formula $(CH_3)_3COH$ is a member of this class.

Tertiary alcohols yield on oxidation compounds which contain a smaller number of carbon atoms than is present in the alcohol.

76. *n-Propyl alcohol*, $CH_3CH_2CH_2OH$, is formed in small quantities in the fermentation of sugars and is obtained as a by-product in the manufacture of ethyl alcohol. It boils at 97.8°, mixes with water, and has the density 0.804 at $\frac{20°}{4°}$. Propyl alcohol resembles ethyl alcohol in chemical properties. It is converted by oxidizing agents into propionic aldehyde and propionic acid, and has the structure $CH_3CH_2CH_2OH$. It is a *normal* primary alcohol. Alcohols which contain carbon atoms linked in a straight chain, and in which the hydroxyl group is joined to an *end* carbon atom, are designated by the prefix *normal*, which is usually abbreviated to the letter *n* in writing. Thus, the alcohol to which is assigned the formula $CH_3CH_2CH_2CH_2OH$ is called *n*-butyl alcohol.

77. *iso-Propyl alcohol*, $(CH_3)_2CHOH$, can be prepared by reducing acetone, $(CH_3)_2CO$:

$$(CH_3)_2C:O^1 + 2H = (CH_3)_2CHOH$$

The hydrogen required is produced by the action of water on sodium amalgam, which is made by heating mercury with about 3 per cent of its weight of sodium. The amalgam so prepared is a solid and can be readily powdered. When it is treated with water the sodium present reacts slowly and hydrogen is evolved. Sodium amalgam and water are often used to reduce organic compounds. The reduction can also be accomplished by passing the vapor of acetone and hydrogen over finely divided nickel at 120°. Isopropyl alcohol can be prepared by heating isopropyl iodide with water for a number of hours, or by boiling the iodide with lead hydroxide.

The alcohol is manufactured on the large scale from the gases obtained when petroleum is cracked to make gasoline. When the gases are passed into sulphuric acid, the propylene which they contain unites with the acid:

$$CH_3.CH{=}CH_2 + H_2SO_4 = CH_3.CHSO_4H.CH_3$$

In the addition that takes place at the double bond, the SO_4H radical adds to the central carbon atom and the hydrogen to

[1] A double bond is often represented by two dots, thus— C :O.

the end carbon atom. When the isopropylsulphuric acid thus formed is warmed with a small amount of water it is hydrolyzed and isopropyl alcohol is formed:

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CH.SO_4H + HOH = \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CHOH + H_2SO_4$$

As large quantities of oils are cracked, the supply of propylene is adequate for the production of enough isopropyl alcohol to meet any industrial demands for the compound that may arise. It is probable that this industrial product may replace ethyl alcohol for many purposes. Before the application of this method of preparing the alcohol was made, the gases formed in cracking petroleum were burned under the stills.

Isopropyl alcohol resembles other alcohols in showing the chemical properties characteristic of compounds which contain an alcoholic hydroxyl group. Its oxidation to acetone shows that it is a secondary alcohol and leads to the conclusion that its structure is represented by the formula $(CH_3)_2CHOH$. Isopropyl alcohol boils at 82.3° and has the specific gravity 0.786 at $\frac{20°}{4°}$.

78. Butyl Alcohols, C_4H_9OH.—Four butyl alcohols are known and four are possible according to the structure theory, if we consider alcohols as hydroxyl derivatives of the hydrocarbons. The formulas of the isomeric hydroxyl substitution products of the two butanes are as follows:

(1) $CH_3CH_2CH_2CH_2OH$ *n*-butyl alcohol, primary

(2) $(CH_3)_2CHCH_2OH$ *iso*-butyl alcohol, primary

(3) $\begin{matrix} CH_3CH_2 \\ CH_3 \end{matrix}\!\!>\!CHOH$ *sec.*-butyl alcohol, secondary

(4) $(CH_3)_3COH$ *tert.*-butyl alcohol, tertiary

The first two formulas represent primary alcohols. Two butyl alcohols occur in fusel oil. As they are both oxidized to the corresponding aldehyde they have been assigned formulas (1) and (2). One of these alcohols can be prepared from *n*-butane. To this one is given formula (1). The physical properties of the butyl alcohols are given in the table in Sec. **84**.

Normal butyl alcohol is prepared from starch on a large scale by a fermentation process which yields at the same time acetone

(**198**). It is used as a solvent and in the preparation of butyl acetate and dibutyl phthalate which are important constituents of certain lacquers made from nitrated cellulose.

sec.-Butyl alcohol can be prepared from methyl ethyl ketone, $\begin{matrix}CH_3\\ \\ C_2H_5\end{matrix}\!\!\rangle CO$, by reduction with hydrogen. Oxidizing agents convert it into the ketone. The alcohol is now made on an industrial scale from the butylene formed as one of the products of the cracking of petroleum:

$$CH_3CH_2CH{=}CH_2 + H_2O = CH_3CH_2\underset{\displaystyle OH}{\underset{|}{C}}HCH_3$$

The hydrocarbon is absorbed in strong sulphuric acid, which is subsequently diluted with water and distilled. The dilute alcohol so obtained is rectified by distillation. The esters of the alcohol are excellent solvents.

tert.-Butyl alcohol is manufactured from the isobutylene $(CH_3)_2C{=}CH_2$, formed in the cracking of petroleum. It adds water in the presence of sulphuric acid more readily than do the butylenes containing a straight chain of carbon atoms:

$$(CH_3)_2C{=}CH_2 + H_2O = (CH_3)_2\underset{\displaystyle OH}{\underset{|}{C}}{-}CH_3$$

For this reason it is absorbed by a more dilute acid than that used in the preparation of *sec.*-butyl alcohol.

By passing a mixture of the butylenes through two solutions of the acid of different concentrations it is possible to absorb largely isobutylene in one, and butene-1 and butene-2 in the other. In this way the two alcohols are obtained separately from a mixture of the hydrocarbons.

tert.-Butyl alcohol can be prepared from acetone by a reaction that is applicable in the preparation of other tertiary alcohols (**85**).

79. The reactivity of the hydroxyl group in *tert.*-butyl alcohol is quite different from that of the same group in primary alcohols. Both classes of alcohols react with sodium and the hydrogen of the hydroxyl group is replaced by the metal. In the case of the primary alcohol the reaction takes place rapidly, whereas to

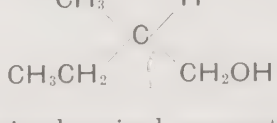
effect the replacement in the tertiary alcohol the substances must be heated together for a long time. On the other hand, primary alcohols react very slowly even at elevated temperatures with a concentrated solution of hydrochloric acid. Tertiary alcohols are converted into chlorides rapidly at room temperature by this reagent.

80. Amyl Alcohols, $C_5H_{11}OH$.—The structural formulas of the amyl alcohols can be readily deduced by substituting hydroxyl groups in the three pentanes, replacing in each case the hydrogen atoms that bear different relations to the molecule. The application of the structure theory to the case of the amyl alcohols leads to the conclusion that eight alcohols of the formula $C_5H_{11}OH$ are possible. Eight alcohols, the reactions of which are in accord with the structural formulas deduced in this way, are known. The most important of these are the two that are found in fusel oil and in recently distilled whisky and brandy. The mixture of amyl alcohols obtained as the result of the fermentation of sugars in the preparation of ethyl alcohol, consists of about 80 to 90 per cent isoamyl alcohol, $(CH_3)_2CHCH_2CH_2OH$, and 10 to 20 per cent active amyl alcohol, $\begin{matrix} CH_3 \\ C_2H_5 \end{matrix}\!\!>\!CHCH_2OH$. The latter is so called because it rotates the plane of polarized light. They are both primary alcohols—a fact which is shown by a study of the products formed from them on oxidation. The two alcohols yield aldehydes and acids which contain five carbon atoms. Isoamyl alcohol has a characteristic unpleasant odor, is poisonous, boils at 130.5°, and is soluble in 50 parts of water. It causes, in part, the disagreeable effects of intoxication by brandy, etc. It is used in large quantities for making isoamyl acetate, which is the basis for certain lacquers and varnishes.

Amyl alcohols are *prepared industrially* from the pentanes isolated from petroleum. The hydrocarbons are first converted into monohalogen derivatives by treatment with chlorine, and the resulting chlorides are heated with steam in the presence of lime. As the result of hydrolysis the halogen atom in each compound is replaced by a hydroxyl group. A number of primary and secondary amyl alcohols are prepared in this way.

81. Optical Activity: Stereochemistry.—The study of active amyl alcohol and other substances that rotate the plane of

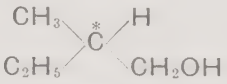
polarized light has led to the discovery of a class of isomerism which is not explained by the structure theory of organic compounds as it has been developed up to this point. Three amyl alcohols are known to which the structure



must be given. Their chemical properties are all in accord with this view of their structure. They differ, however, in their effect on polarized light. One alcohol rotates the plane of polarization to the right, one to the left, and the third is without effect. Those which rotate the plane of polarization are said to be *optically active*. As the differences in properties observed in these compounds are all of a physical nature, it might be assumed that these differences resulted from varying arrangements of the molecules and that the cause was purely physical. We are familiar with inorganic substances which crystallize in two forms, possessing markedly different physical properties. But this cannot be the explanation in the case of the amyl alcohols under consideration, as their characteristic action on polarized light is not affected by converting them into vapor. Properties which are dependent upon molecular aggregation disappear when the substance possessing these properties is converted into vapor. For example, the vapor of red phosphorus and that of yellow phosphorus are the same. Further, optically active compounds exhibit their characteristic effect on polarized light when they are in solution. In this condition free molecular motion is probably possible.

An extension of the structure theory serves to explain adequately the isomerism of the amyl alcohols and other optically active compounds. This extension takes into account the arrangement of the atoms in space. Many compounds are known which resemble the amyl alcohols in their action on polarized light. An examination of the structure of these compounds brings out the fact that they, in nearly all cases, contain a carbon atom to which are joined four different atoms or groups. Such a carbon atom is said to be *asymmetric*. In the case of active amyl alcohol there is one carbon atom which is in combina-

tion with the groups CH_3, C_2H_5, H, and CH_2OH. This asymmetric atom is marked with an asterisk (*) in the following formula:



A consideration of the possibilities of the arrangement of such a compound as this in space leads to the conclusion that isomerism should exist. Such an arrangement cannot be readily illustrated on a plane surface, as it involves three dimensions. It can be appreciated best by considering a carbon atom as placed in the center of a regular tetrahedron, the affinities of the carbon atom being directed to the four angles of the tetrahedron. Such an arrangement is represented by Fig. 3.[1] If the affinities

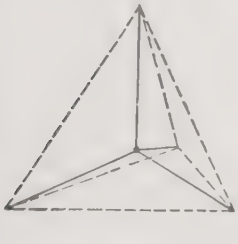


FIG. 3.

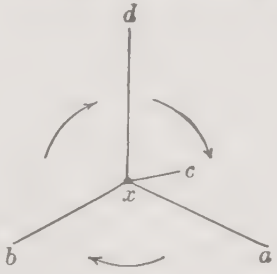


FIG. 4.

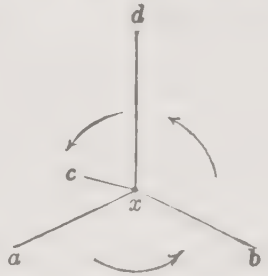


FIG. 5.

of a carbon atom are directed in this way, isomerism among substitution products is possible only in the case where the four atoms or groups in combination with the carbon atom are different. The isomerism in the case of compounds with four different atoms is represented by Fig. 4 and Fig. 5.

The two arrangements are not identical, as they cannot be superimposed. They bear to each other the relation of the right and the left hand—of an object and its reflection in a mirror. Suppose that a ray of polarized light passes through the two molecules represented by Fig. 4 and Fig. 5, the direction of the advancing beam being, in both cases, along the line *cx*. Further, suppose that the atoms situated at *a*, *b*, and *d* cause the plane of

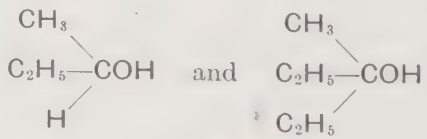
[1] The space relations involved can be more readily understood by a study of models. These can be made from pieces of cork of different size or shape, and stout wires pointed at both ends.

the vibrations to be turned in the direction which is indicated by passing from *a* to *b* to *d*. In the case of the configuration represented by Fig. 4 the rotation would be in the direction of the motion of the hands of a clock; in the second case, Fig. 5, the rotation would be in the opposite direction. Substances which rotate the plane of polarization in the first way when they are examined in a polariscope are said to be dextrorotatory. Those which rotate the plane of polarization in the opposite direction are said to be levorotatory. A mixture of the two optically active compounds in equal amounts produces what is called the inactive compound. The mixture is inactive as the extent to which the plane of polarization is rotated is the same in the case of the two isomers. The three forms are indicated by prefixing to the name of the compound the letters *d*, *l*, or *dl;* thus, *d*-amyl alcohol. The important subject of optical activity will be discussed more in detail later (**308, 322**).

Higher Monohydroxy Alcohols

82. A large number of the homologues of methyl alcohol are known. The naturally occurring alcohols which contain a large number of carbon atoms have the normal structure. Among these may be mentioned cetyl alcohol, $C_{16}H_{33}OH$, which is obtained from spermaceti, and myricyl alcohol, $C_{30}H_{61}OH$, which is obtained from beeswax.

Nomenclature of Alcohols.—Two systematic methods of naming alcohols are in use. In one, the alcohol is considered as a substitution product of methyl alcohol, which is called carbinol. Thus the alcohols having the structures represented by the formulas



are called methylethyl-carbinol and methyldiethyl-carbinol, respectively.

In the Geneva nomenclature the name of the alcohol is formed by replacing the final *e* in the name of the hydrocarbon from which the alcohol is derived by the ending *ol*. Thus,

ethyl alcohol is ethanol, and the alcohol with the structure $CH_2{=}CHCH_2OH$ is propenol. The position of the hydroxyl group is shown by adding to the name of the alcohol a number which indicates the position of the group in relation to the carbon atoms in the chain. Thus $CH_3.CH_2.CH_2.CH_2OH$ is butanol-1 and $CH_3.CH_2.CHOH.CH_3$ is butanol-2. In the case of alcohols which are not normal, *i.e.*, those in which the carbon atoms are not in a straight chain, the alcohol is considered as a substitution product of a normal hydrocarbon which contains both alkyl groups and a hydroxyl group. In naming a compound the longest straight chain of carbon atoms is selected as representing the carbon atoms in the hydrocarbon of which the alcohol is a derivative, thus, isoamyl alcohol, $CH_3CHCH_2CH_2OH$, is 2-

CH_3

methyl-butanol-4. In the modified Geneva system used in American chemical publications the alcohol is named 3-methyl-butanol-1. The systems just described prove useful in naming alcohols which possess a more or less complex structure.

Alcohols which contain two hydroxyl groups are named in a similar way. The number of hydroxyl groups is indicated by prefixing the syllables *di*, *tri*, etc., to the termination *ol*. Thus, the dihydroxy alcohol $CH_3.CHOH.CH_2OH$ is called propanediol-1, 2.

83. Properties of the Saturated Alcohols Containing One Hydroxyl Group.—The melting points, boiling points, and specific gravities of some of the members of this series of alcohols are given in the table on p. 96. The data refer to the normal primary alcohols.

An examination of the table shows that the increase in boiling point as we pass from one member to the next in the series up to the alcohol with ten carbon atoms is nearly constant, 18° to 20°. The difference between the boiling points of methyl alcohol and ethyl alcohol is only 14°, however. Irregularities like this are noticed in other homologous series. The difference between the boiling points of adjacent members of the series which contain a large number of carbon atoms is less than 18°. As the molecule increases in weight, the introduction of one carbon and two hydrogen atoms has less effect on the physical properties of the resulting molecule. This fact is observed in other homolo-

gous series. The change in the specific gravity with increase in molecular weight shows some regularity if we disregard methyl alcohol.

NORMAL PRIMARY ALCOHOLS, $C_nH_{2n+2}O$

Name	Formula	Melting point, °C.	Boiling point at 760 mm., °C.	Density, $\frac{25°}{4°}$
Methyl	CH_3OH	− 97.8	64.5	0.792
Ethyl	C_2H_5OH	−117.3	78.5	0.789
Propyl	C_3H_7OH	−127	97.8	0.804
Butyl	C_4H_9OH	− 89.8	117.7	0.810
Amyl	$C_5H_{11}OH$	− 78.5	137.9	$0.817^{\frac{20°}{20°}}$
Hexyl	$C_6H_{13}OH$	− 51.6	155.8	0.820
Heptyl	$C_7H_{15}OH$	− 34.6	175.8	$0.817^{22°}$
Octyl	$C_8H_{17}OH$	− 16.3	194	0.827
Nonyl	$C_9H_{19}OH$	− 5	215	0.828
Decyl	$C_{10}H_{21}OH$	7	231	0.829
Hendecyl (undecyl)	$C_{11}H_{23}OH$	19	$146^{30mm.}$	0.833
Dodecyl	$C_{12}H_{25}OH$	24	259	0.831
Tridecyl	$C_{13}H_{27}OH$	30.5	$156^{15mm.}$	0.822 (m.p.)
Tetradecyl	$C_{14}H_{29}OH$	38	$167^{15mm.}$	0.824 (m.p.)
Pentadecyl	$C_{15}H_{31}OH$	46		
Hexadecyl (cetyl)	$C_{16}H_{33}OH$	49.3	344	0.817 (m.p.)

84. The effect of structure on the physical properties is shown in the following table of the properties of the isomeric butyl alcohols:

BUTYL ALCOHOLS

Name	Formula	Melting point, °C.	Boiling point at 760 mm., °C.	Density, $\frac{20°}{4°}$
n-Butyl	$CH_3CH_2CH_2CH_2OH$	− 89.8	117.7	0.810
iso-Butyl	$(CH_3)_2CHCH_2OH$	−108	107.3	0.802
sec.-Butyl	$CH_3CH_2CHOHCH_3$	.....	99.5	0.808
tert.-Butyl	$(CH_3)_3COH$	25.5	82.8	0.789

The most notable fact observed in this table is that the tertiary alcohol has the lowest boiling point and density. The

student should compare the relations observed here with those that exist in the case of the isomeric pentanes.

85. General Methods of Preparing Alcohols. *By the Hydrolysis of Alkyl Halides.*—It has already been stated that an alcohol can be prepared by replacing a halogen atom in alkyl halides by a hydroxyl group. This replacement can be effected by treating the halide with water or a metallic hydroxide. The preparation of methyl alcohol from methyl iodide is typical:

$$CH_3I + AgOH = CH_3OH + AgI$$

The readiness with which this reaction takes place varies with the nature of the group and with the halogen. Iodides react more readily than the bromides, which in general are more reactive than the chlorides. This method of preparation is an example of a general method of wide applicability.

From Alkyl Esters.—The alkyl halides are ethereal salts of the alcohols and the hydrides of the halogens—ethyl iodide is the ethereal salt, or ester, made from ethyl alcohol and hydriodic acid. Other acids form ethereal salts; ethyl sulphate, acid ethyl sulphate, ethyl nitrate, ethyl acetate, etc., are well-known substances. These esters are hydrolyzed by water just as ethyl iodide is, and alcohol and the corresponding acids are formed. This reaction—the hydrolysis of an ester—serves therefore as a convenient way of preparing alcohols. The preparation of isopropyl alcohol by means of the following reaction is an illustration of the method:

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CHSO_4H + HOH = \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CHOH + H_2SO_4$$

It will be remembered that acid esters of sulphuric acid can be prepared by the action of the acid on unsaturated hydrocarbons The preparation of alcohols from unsaturated hydrocarbons through the esters of sulphuric acid is a convenient method, as the esters of acids which contain oxygen are much more easily hydrolyzed than are the esters of the halogen hydrides. Acid ethyl sulphate is readily hydrolyzed when boiled with water. Ethyl acetate is converted into ethyl alcohol and sodium acetate when warmed with an aqueous solution of sodium hydroxide.

By Reduction of Aldehydes and Ketones.—Alcohols can also be prepared by reducing aldehydes. This reaction is the reverse

of that by which primary alcohols are converted into aldehydes by oxidation. As a consequence, primary alcohols are obtained. When aldehyde is treated with sodium amalgam, or a mixture of aldehyde vapor and hydrogen is passed over finely divided nickel, alcohol is formed:

$$CH_3CHO + 2H = CH_3CH_2OH$$

The reduction of ketones in the same manner yields secondary alcohols:

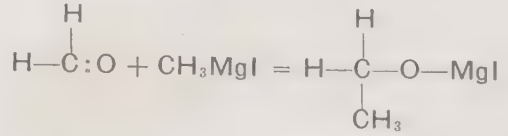
$$(CH_3)_2CO + 2H = (CH_3)_2CHOH$$

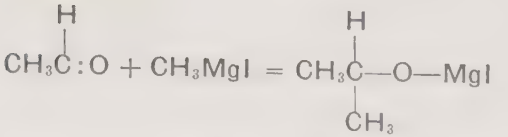
By the Grignard Reaction.—Primary, secondary, and tertiary alcohols can be prepared by the action of alkyl halides and magnesium on aldehydes and ketones. When magnesium is added to a solution of an alkyl halide in ether, the metal and the halide unite:

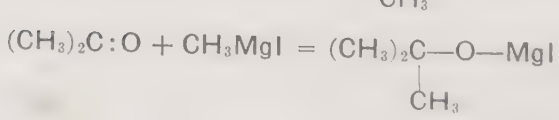
$$CH_3I + Mg = CH_3MgI$$

The use of such compounds in syntheses was investigated by Grignard.

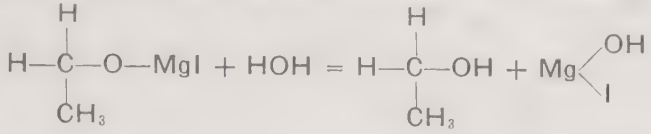
The compound so formed will unite with an aldehyde or a ketone and an addition product is obtained. The addition is brought about as the result of the presence in the aldehyde or ketone of the group C=O. In the addition, the double linking between the carbon and oxygen atom is broken; the alkyl group joins to the carbon atom and the magnesium and halogen to the oxygen. The reaction in the case of formaldehyde, HCHO, acetaldehyde, CH_3CHO, and acetone, $(CH_3)_2CO$, respectively, is represented by the following equations:

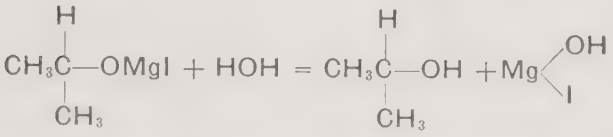


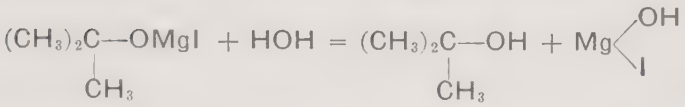




These addition products are decomposed by water thus:







In the case of formaldehyde a primary alcohol is obtained; other aldehydes yield secondary alcohols; and ketones, tertiary alcohols. From an aldehyde we obtain a primary alcohol by reduction, and a secondary alcohol by making use of the Grignard reaction. In the same ways we can convert a ketone into a secondary or tertiary alcohol. The Grignard reaction is of great value in synthetic organic chemistry. It can be used to prepare compounds other than alcohols.

86. The Relative Reactivities of Primary, Secondary, and Tertiary Alcohols.—The hydroxyl groups of alcohols enter into a number of typical reactions. For example, the hydrogen atom of this group is replaced by sodium in all alcohols when they are treated with the metal. The ease with which the replacement takes place, as measured by the rapidity of the reaction, varies from alcohol to alcohol. These differences result from the fact that the bond between the hydrogen and oxygen atoms in the hydroxyl group is affected by the structure of the radical in combination with this group.

The hydrogen atom of the hydroxyl group in methyl alcohol is more reactive than the similar atom in *tert.*-butyl alcohol. Comparative reactivities in this sense can be measured by determining the rates at which similar reactions take place between a fixed reagent and the compounds studied.

The relative reactivities of the hydroxyl-hydrogen in a number of alcohols have been determined by measuring the rates at which these alcohols react with an acyl chloride:

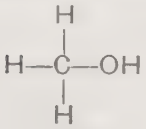
$$ROH + R'COCl = R'COOR + HCl$$

For convenience paranitrobenzoyl chloride, $NO_2C_6H_4COCl$, was used. The relative rates of the several reactions are shown in the case of the normal primary alcohols by the following numbers:

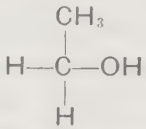
Methanol	Ethanol	Propanol	Butanol	Pentanol	Hexanol
100	45.7	35.9	38.2	42.9	45.6

The hydroxyl-hydrogen in methanol is over twice as reactive as that of ethanol, when measured in this way. The differences between the influence of the primary alkyl radicals other than methyl on this hydrogen are not great.

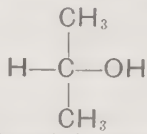
The replacement of hydrogen atoms in methyl alcohol by radicals has a marked effect on the hydrogen of the hydroxyl group as shown by the following relative rates:



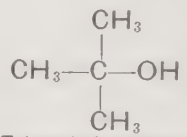
Carbinol
100



Methyl-carbinol
45.7



Dimethyl-carbinol
5.4

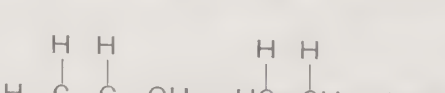


Trimethyl-carbinol
1.4

The relative reactivities measured in this way, by means of an acyl chloride, are also shown in the case of these alcohols when measured by other reagents.

The structure of the alkyl radical in alcohols affects, in a marked degree, the reactivity of the hydroxyl group; the bond between this group and the carbon atom to which it is joined varies widely in strength in different alcohols. It has already been pointed out that the hydroxyl group in primary alcohols is replaced slowly by chlorine when these alcohols are treated with concentrated hydrochloric acid, whereas tertiary alcohols react rapidly with this reagent at room temperature.

Differences between the reactivities of the hydroxyl groups in alcohols are shown when these compounds are converted by heat into water and unsaturated hydrocarbons. In each case the bond linking the hydroxyl group to carbon is broken. For example:



Primary alcohols are stable at 360° C. (the boiling point of mercury); secondary alcohols decompose at this temperature into

water and an olefin, but are stable at 218° (the boiling point of naphthalene); tertiary alcohols are converted into olefins at the latter temperature.

87. Reactions of Alcohols of Analytical Significance.—A number of reactions of alcohols have been described in connection with the consideration of the members of this series. A few of these are of special value in determining whether an unknown substance is an alcohol. All alcohols react with sodium with the evolution of hydrogen. In certain cases gentle heat is necessary to bring about the reaction. In testing a substance for the presence of a hydroxyl group in this way, it is necessary to make sure that the substance is free from water. As many substances which are not alcohols contain a hydroxyl group and consequently react with sodium, and as certain compounds which do not contain this group show a similar reaction, the formation of hydrogen when an unknown substance is treated with sodium is not a proof that the substance is an alcohol. The test is, however, of value. If no reaction takes place with the metal the substance is not an alcohol.

Many alcohols dissolve in concentrated sulphuric acid as the result of the formation of alkylsulphuric acids. Others are converted into unsaturated hydrocarbons by this reagent, especially if the temperature is allowed to rise as the result of the chemical reaction between the two substances. The alcohols of high molecular weight do not react readily with concentrated sulphuric acid, and in certain cases are insoluble. The test with this acid is not conclusive, therefore, although it is usually made and is often of value as confirmatory evidence. Many compounds which contain oxygen, either in the form of a hydroxyl group or in combination with carbon in other ways, dissolve in concentrated sulphuric acid.

Alcohols react with the chlorides of acids. In applying this reaction in testing for alcohol, acetyl chloride is frequently used. Most alcohols react with acetyl chloride and form hydrogen chloride and the corresponding ester of acetic acid. The reaction between ethyl alcohol and acetyl chloride is expressed by the following equation:

$$C_2H_5OH + CH_3COCl = CH_3COOC_2H_5 + HCl$$

The evolution of hydrogen chloride when a substance is treated with acetyl chloride is evidence that it may be an alcohol. The esters formed are usually insoluble in water, and in most cases possess characteristic odors. A positive test, however, is not conclusive, as certain compounds which contain a hydroxyl group but are not alcohols act in the way described.

A convenient method of identifying alcohols is to treat them with the chloride of dinitrobenzoic acid $(NO_2)_2C_6H_3.COCl$. This chloride is used because its esters are in nearly all cases solids that crystallize well. It is possible, therefore, to identify but small quantities of an alcohol because much smaller amounts of a substance can be purified by crystallization than by distillation, which must be used in the case of liquids.

The most characteristic reaction of the monohydroxy alcohols is their behavior when heated with an aqueous solution of hydrobromic acid which is saturated at its boiling point—the so-called constant-boiling mixture which contains about 49 per cent of hydrogen bromide. When heated to boiling with this reagent monohydroxy alcohols are converted into bromides. Whether a reaction has taken place can be easily told. The bromides are all insoluble in, and heavier than, water, whereas the alcohols are all lighter than water.

Problems

1. Write equations for reactions which can be used to prepare (*a*) primary, (*b*) secondary, and (*c*) tertiary alcohols.

2. Write equations for reactions that show the chemical behavior of ethyl alcohol with (*a*) cold H_2SO_4, (*b*) hot H_2SO_4, (*c*) HI, (*d*) PBr_3, (*e*) CH_3COOH, (*f*) CH_3COCl, (*g*) Na, (*h*) $(CH_3CO)_2O$, (*i*) an aqueous solution of $K_2Cr_2O_7$, and H_2SO_4.

3. (*a*) Write the graphic formulas of the alcohols having the composition $C_5H_{11}OH$. (*b*) Name the alcohols according to the two systems explained in Sec. **82**. (*c*) Indicate which of the alcohols are primary, secondary, and tertiary and (*d*) which contains an asymmetric carbon atom.

4. How could you distinguish by chemical tests the following: (*a*) hexyl alcohol and hexane, (*b*) *tert.*-butyl alcohol and isobutyl alcohol, (*c*) ethyl alcohol and methyl alcohol, (*d*) propyl alcohol and isopropyl alcohol?

5. A compound of the composition $C_6H_{10}O_5$ was converted into one of the composition $C_{12}H_{16}O_8$ when treated with acetic anhydride. How many alcoholic hydroxyl groups did the original substance contain?

6. A compound having the formula $C_2H_6O_2$ was converted by acetyl chloride into one having the formula $C_6H_{10}O_4$. Write the graphic formula of the two compounds.

7. Write the graphic formulas of all the compounds containing three carbon atoms that could be obtained theoretically as the result of the oxidation of (*a*) $CH_2OH.CH_2.CH_2OH$ and (*b*) $CH_3.CHOH.CH_2OH$.

8. Write equations for reactions by which could be obtained (*a*) isopropyl alcohol from propyl alcohol, (*b*) propyl alcohol from isopropyl alcohol, and (*c*) *tert.*-butyl alcohol from isopropyl alcohol.

9. How do the solubilities of alcohols in water change with increase in molecular weight? How could you distinguish readily propyl alcohol from isoamyl alcohol?

10. Plot on coordinate paper, against the number of carbon atoms, the boiling points of the paraffins, olefins, and the normal primary saturated alcohols containing from one to eight carbon atoms. State the effect on the boiling point of (*a*) the removal of two hydrogen atoms from the saturated hydrocarbons, and (*b*) the replacement of hydrogen by the hydroxyl group.

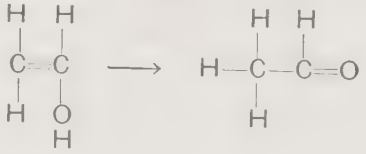
11. Compare the densities of the paraffins, olefins, and saturated alcohols, and make statements in regard to the effect of the following changes in structure on density: (*a*) $-CH_2CH_3$ to $-CH{=}CH_2$, (*b*) $-CH_2CH_3$ to $-CH_2CH_2OH$. Which of the following would you expect to have the greater density: (*c*) $CH_3CH_2CH_2OH$ or $CH_2{=}CHCH_2OH$, (*d*) CH_3CH_2-CH_2COOH or $CH_2{=}CHCH_2COOH$? Record the densities of the four compounds.

CHAPTER VI

UNSATURATED ALCOHOLS. POLYHYDROXY ALCOHOLS

88. A number of alcohols which are derivatives of the unsaturated hydrocarbons are known. The chemistry of these compounds will be illustrated by a consideration of a few typical members of the series.

Vinyl alcohol, $CH_2{=}CHOH$, which is the hydroxyl derivative of ethylene, has never been isolated. Reactions which should produce a compound of this structure lead to the formation of aldehyde; it is probable that vinyl alcohol is first produced, and that aldehyde is formed by a rearrangement of the atoms in the molecule:



Rearrangements similar to this have been shown definitely to take place in the case of other compounds. No simple alcohol is known in which a hydroxyl group is in combination with a carbon atom united to another carbon atom by a double bond.

89. Allyl Alcohol, $CH_2{=}CHCH_2OH$.—According to the structure theory, three monohydroxyl derivatives of propylene are possible: $CH_2{=}CHCH_2OH$, $CH_2{=}COHCH_3$, and $CHOH{=}CHCH_3$. Allyl alcohol, the structure of which is represented by the first formula, is the only one known. In the second and third formulas the hydroxyl groups are represented in combination with a doubly linked carbon atom. Attempts to prepare these compounds have yielded results similar to those obtained in the case of vinyl alcohol; isomeric compounds have been obtained in both cases as the result of molecular rearrangement. Derivatives of these alcohols are known, however.

Allyl alcohol occurs in small quantities in pyroligneous acid. A number of derivatives of allyl alcohol occur in nature. Allyl sulphide, $(C_3H_5)_2S$, is the chief constituent of oil of garlic. Allyl isothiocyanate, C_3H_5NCS, occurs in mustard seed in combination with glucose. Allyl alcohol is a colorless liquid of pungent odor, which mixes with water in all proportions and boils at 97°. Its specific gravity is 0.855 at $\frac{20°}{4°}$. It can be prepared in a number of ways which are suggested by a consideration of its structural formula. It is most conveniently prepared by heating glycerol with oxalic acid. The reaction, which is a complicated one, will be discussed later (**105**).

The reactions of allyl alcohol are in accord with the structure assigned to it. The presence of a hydroxyl group is shown by the fact that the substance reacts with sodium with the evolution of hydrogen, and by the fact that allyl acetate is formed when it is treated with acetyl chloride. The presence of a double bond in allyl alcohol is shown by the fact that it unites readily with two atoms of chlorine, bromine, or iodine. It shows, in general, the reactions which are characteristic of ethylene and its homologues. The structure of the alcohol follows from the reactions which have been mentioned and from the fact that by careful oxidation it can be converted into an aldehyde and an acid which contains the same number of carbon atoms as the alcohol. It contains, therefore, a primary alcohol group, $—CH_2OH$. Allyl alcohol, when reduced by hydrogen formed by the action of zinc on dilute sulphuric acid, is converted into *n*-propyl alcohol. This indicates that the hydroxyl group in allyl alcohol is joined to an end carbon atom.

The presence of the unsaturated carbon atoms in allyl alcohol has a marked effect on the reactivity of the hydroxyl group. The alcohol is converted into allyl chloride when it is warmed with an aqueous solution of hydrochloric acid. A similar reaction does not take place with propyl alcohol.

90. Propargyl alcohol, $HC\equiv C.CH_2OH$, is an illustration of an alcohol derived from a hydrocarbon of the acetylene series. The compound is a colorless liquid of peculiar odor, which dissolves in water. It boils at 115° and has the density 0.972 at $\frac{25°}{4°}$. It can be prepared by methods which involve the principles made use of in the preparation of alcohols and of triple-

bonded compounds. One method is illustrated by the following formulas:

$$CH_2Br.CHBr.CH_2Br \xrightarrow{\text{alc. KOH}} CH_2:CBr.CH_2Br \xrightarrow{H_2O}$$

$$CH_2:CBr.CH_2OH \xrightarrow{\text{alc. KOH}} CH:C.CH_2OH$$

The method involves the preparation of an alcohol by replacing a halogen atom by the hydroxyl group, and the establishment of the triple bond by the removal of two molecules of hydrogen bromide from adjacent carbon atoms. Propargyl alcohol exhibits the reactions of a primary alcohol, which have been frequently emphasized. It shows its relation to acetylene by forming well-characterized metallic derivatives. The copper compound $CuC{\equiv}C.CH_2OH$ is a canary-yellow powder which is formed by treating an ammoniacal solution of cuprous chloride with the alcohol. It explodes when heated.

Polyhydroxy Alcohols

91. Glycol, $C_2H_4(OH)_2$, and glycerol, $C_3H_5(OH)_3$, are examples of alcohols that contain two and three hydroxyl groups, respectively. Alcohols are known which contain four, five, and six hydroxyl groups.

The simplest alcohol containing two hydroxyl groups would have the structure $CH_2(OH)_2$. This compound does not exist, although derivatives in which the two hydrogen atoms of the hydroxyl groups are replaced by radicals are known. It has been stated that, in general, two hydroxyl groups cannot exist in combination with a single carbon atom. When an attempt is made to prepare such a compound, instead of obtaining the grouping represented by the formula $=C\langle^{OH}_{OH}$, the elements of water are lost and the resulting compound contains the group $=C=O$. Alcohols contain, therefore, at least as many carbon atoms as hydroxyl groups.

92. Glycols.—This is the general name given to the alcohols which contain two hydroxyl groups. *Glycol*, $CH_2OH.CH_2OH$, the first member of the series, is a colorless liquid which mixes with water and has a sweet taste. It boils at 197.5° and after

solidification in a freezing mixture melts at $-17.4°$. It is heavier than water as it has the specific gravity 1.115 at $\frac{20°}{4°}$. It will be recalled that the alcohols with one hydroxyl group are lighter than water.

Preparation.—Glycol may be prepared from ethylene bromide by replacing the halogen atoms by hydroxyl groups. This exchange can be effected by heating the bromide either with water at a high temperature in a sealed tube, or with a solution of sodium carbonate in an open vessel. As the reaction takes place slowly, glycol is sometimes prepared by heating ethylene bromide with silver or potassium acetate and then hydrolyzing the resulting acetate. The changes are represented by the following equations:

$$C_2H_4Br_2 + 2CH_3COOAg = C_2H_4(OOCCH_3)_2 + 2AgBr$$
$$C_2H_4(OOCCH_3)_2 + 2KOH = C_2H_4(OH)_2 + 2CH_3COOK$$

93. *Manufacture.*—A method has recently been developed to prepare glycol on an industrial scale from ethylene obtained either from alcohol or from the gases formed when oils are cracked at high temperatures. The gas is passed into a solution of hypochlorous acid, HOCl, prepared from bleaching powder and carbon dioxide, or into water along with chlorine. The latter reacts with the water, $Cl_2 + H_2O = HOCl + HCl$, and the hypochlorous acid formed adds to the ethylene. The compound formed, ethylene chlorohydrin, $CH_2OH.CH_2Cl$, is soluble in water and volatile with steam. It is separated by distillation and heated with a solution of sodium bicarbonate, which reacts with the hydrochloric acid formed in the hydrolysis:

$$CH_2OH.CH_2Cl + HOH = CH_2OH.CH_2OH + HCl$$

This method makes it possible to prepare ethylene chlorohydrin and glycol on a large scale from cheap materials.

94. *Reactions.*—The behavior of glycol with reagents indicates that the compound contains two alcoholic hydroxyl groups. With sodium it forms the compounds $CH_2OH.CH_2ONa$ and $CH_2ONa.CH_2ONa$. Phosphorus pentachloride or hydrochloric acid replaces, according to the conditions, one or two hydroxyl groups by chlorine. When treated with cold nitric acid one of the primary alcohol groups is oxidized to carboxyl, and an acid of

the structure $\begin{matrix}CH_2OH\\|\\COOH\end{matrix}$ (glycolic acid) is formed. When the mixture of the alcohol and dilute nitric acid is heated oxalic acid, $\begin{matrix}COOH\\|\\COOH\end{matrix}$, is obtained.

Uses.—Glycol is converted by a mixture of nitric and sulphuric acids into a dinitrate, $C_2H_4(NO_3)_2$, which explodes when detonated. It resembles in structure nitroglycerin, $C_3H_5(NO_3)_3$, and is used in certain kinds of dynamite (**101**).

A mixture of glycol and water is used in automobile radiators on account of the fact that the mixture does not freeze at winter temperatures. The compound is sold for this under the name "Prestone." Derivatives of glycol, such as $CH_2OH.CH_2OC_2H_5$, are valuable solvents.

95. *Propylene glycol*, $CH_3.CHOH.CH_2OH$ (b.p. 189°), can be prepared from the propylene formed in the cracking of oils by the methods used to make ethylene glycol. The chlorohydrin and nitrate prepared from it have been fully studied in the way indicated above in the case of corresponding ethylene derivatives; in certain respects they are superior to the latter.

96. *Trimethylene glycol*, $CH_2OH.CH_2.CH_2OH$, is an isomer of propylene glycol. It is found at times in crude glycerin, being produced, in all probability, as the result of a fermentation process. It can be prepared by replacing the bromine atoms in the bromide of the structure CH_2Br-CH_2CH_2Br (**278**). It boils with decomposition at 214°.

97. Glycerol, $C_3H_5(OH)_3$.—Glycerol, the simplest alcohol containing three hydroxyl groups, is a derivative of propane. It has been known for a long time and is commonly called glycerin. Glycerol is a viscous liquid which has the specific gravity 1.260 at $\frac{20°}{4°}$. It has a sweet taste; in this respect it resembles the other polyhydroxy alcohols. When pure it is colorless, melts at 17.9° after solidification in a freezing mixture, and boils without decomposition at 290°. When distilled in the presence of salts slight decomposition takes place. Glycerol is miscible with water, alcohol, and chloroform, but is insoluble in ether. It is hygroscopic and will absorb more than one-half its weight of water from the air. Glycerol is produced in the alcoholic fermentation of sugar and consequently occurs in all

fermented liquors. The amount of glycerol formed in the fermentation is about 3 per cent of the weight of the sugar.

Manufacture.—Glycerol is obtained commercially from animal fats or from oils which occur in plants. These substances consist of mixtures of compounds, called *glycerides*, which are esters of glycerol and organic acids. The esters which occur in largest amounts in the fats and oils are palmitin, $(C_{15}H_{31}.COO)_3C_3H_5$, which is glyceryl palmitate; stearin, $(C_{17}H_{35}.COO)_3C_3H_5$, which is a glyceryl stearate; and olein, $(C_{17}H_{33}.COO)_3C_3H_5$, the glycerol ester of oleic acid—an unsaturated acid of the formula $C_{17}H_{33}.COOH$.

These esters are hydrolyzed when heated with steam or when boiled with a solution of an alkali. Esters are in general converted into acids and alcohols when heated with water. Ethyl acetate under these conditions yields ethyl alcohol and acetic acid:

$$CH_3COOC_2H_5 + HOH = CH_3COOH + C_2H_5OH$$

When palmitin is heated with water to a high temperature a reaction takes place which is represented by the following equation:

$$(C_{15}H_{31}COO)_3C_3H_5 + 3HOH = 3C_{15}H_{31}COOH + C_3H_5(OH)_3$$

Palmitic acid and glycerol are formed. When palmitin is heated with a solution of sodium hydroxide, glycerol and sodium palmitate are formed. This reaction of hydrolysis is usually called *saponification* as the sodium salt of the fatty acid formed is a *soap*. The preparation and properties of soap and the chemical properties of fats will be described later (**125**). The reaction is introduced in this place on account of its bearing on the production of glycerol, which is obtained as a by-product in the manufacture of soap and of candles. The glycerol is separated from the aqueous liquid obtained in these processes by evaporating the solution after precipitating impurities with iron salts. Pure glycerol is obtained by distilling the residue under diminished pressure with superheated steam. The excess of water is removed by evaporating the solution *in vacuo* until the glycerol has the specific gravity of about 1.262.

The conditions under which glycerol is formed as the result of fermentation of sugars have been investigated carefully in

recent years. The war of 1914 to 1918 gave an impetus to the study, as large quantities were required for explosives (**101**) and the supply of fat available for the preparation in the usual way did not appear to be adequate. It was found that if the fermentation is allowed to take place in the presence of from 5 to 6 per cent of sodium sulphite, the yield of glycerol is increased to about 25 per cent.

Uses.—Glycerol is used in large quantities in the manufacture of nitroglycerin. It is also used in the preparation of printers' ink rolls and, on account of its being non-volatile and hygroscopic, as an ingredient of ink used with rubber stamps. It is used in large quantities in the tobacco industry as a preservative; owing to its ability to absorb water from the air it prevents the tobacco from becoming too dry. It is also used in pharmacy, as a sweetening agent in fermented liquors, in confectionery and preserves, and in the preparation of cosmetics.

98. *Synthesis.*—Glycerol has been prepared synthetically by methods which lead to the view that it is a trihydroxy derivative of propane. When the trichloropropane of the structure $CH_2Cl.CHCl.CH_2Cl$ is heated with water at about 170° the halogen atoms are replaced by hydroxyl groups, the reaction being analogous to the preparation of alcohol from ethyl bromide. The equation for the reaction is

$$\begin{array}{l} CH_2Cl \\ | \\ CHCl \\ | \\ CH_2Cl \end{array} + 3HOH = \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} + 3HCl$$

Chemical Properties.—The reactions of glycerol with other substances are in accord with the structure which is arrived at from an interpretation of the methods made use of in its synthesis. The presence of three hydroxyl groups is shown by the composition of the products formed as the result of the action of the chlorides of phosphorus on glycerol. Under the proper conditions phosphorus trichloride will replace one, two, or three hydroxyl groups in glycerol by chlorine atoms. Glycerol, like other alcohols, reacts with strong inorganic acids and forms esters. When it is heated with hydrochloric acid compounds are formed in which one or two hydroxyl groups are replaced by halogen atoms. These substances, which have the structure represented by the

formulas $CH_2OH.CHOH.CH_2Cl$ and $CH_2Cl.CHOH.CH_2Cl$, are called monochloro- and dichlorohydrin, respectively. Hydrobromic acid forms similar compounds.

99. *Reactions with Hydriodic Acid.*—The changes which glycerol undergoes with hydriodic acid are different from those which take place with hydrochloric acid, on account of the fact that hydriodic acid is a strong reducing agent. When glycerol is heated with a concentrated aqueous solution of hydriodic acid the products formed are allyl iodide and propylene. In the presence of an excess of the acid isopropyl iodide results. Allyl iodide and isopropyl iodide are most conveniently prepared by these reactions. The separate chemical reactions by which these substances are formed are not definitely known. In all, however, the hydriodic acid acts as a reducing agent. The effect on the result of the relation between the quantities of glycerol and acid used is shown by the following equations:

$$CH_2OH.CHOH.CH_2OH + 3HI = CH_2{:}CH.CH_2I + 3H_2O + I_2$$
$$CH_2OH.CHOH.CH_2OH + 4HI = CH_2{:}CH.CH_3 + 3H_2O + 2I_2$$
$$CH_2OH.CHOH.CH_2OH + 5HI = CH_3.CHI.CH_3 + 3H_2O + 2I_2$$

It has already been pointed out that the equations used to represent the reactions studied in organic chemistry frequently do not have the quantitative significance that similar equations in inorganic chemistry have. The reactions which organic substances undergo are often complicated in that a number of reactions which can be represented by separate equations are taking place simultaneously. The action of hydriodic acid on glycerol is an example of such a reaction. Similar reactions are known to take place between inorganic compounds. The student will recall what takes place when potassium iodide is treated with concentrated sulphuric acid. The hydriodic acid produced reduces sulphuric acid; and sulphur dioxide, sulphur, and hydrogen sulphide are formed. The equations written for these reactions are as follows:

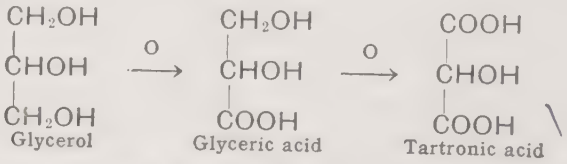
$$H_2SO_4 + 2HI = SO_2 + 2H_2O + I_2$$
$$H_2SO_4 + 6HI = S + 4H_2O + 3I_2$$
$$H_2SO_4 + 8HI = H_2S + 4H_2O + 4I_2$$

If it is desired to use such a reaction as a means of preparing one of the reduction products, careful study of the conditions under which the reaction takes place is necessary in order to discover under what conditions the yield of the desired compound is greatest. To obtain a satisfactory yield of allyl iodide from glycerol, the latter is distilled with phosphorus iodide. It is probable that the three hydroxyl groups are first replaced by iodine and the resulting compound then loses two iodine atoms:

$$CH_2I.CHI.CH_2I = CH_2{:}CH.CH_2I + I_2$$

When a larger proportion of phosphorus iodide is used, and water is present which converts the iodide into hydriodic acid, the chief product of the reaction is isopropyl iodide.

100. *Oxidation of Glycerol.*—Glycerol can be readily oxidized. When, for example, glycerol is placed on powdered potassium permanganate the mixture soon ignites, and the glycerol burns with a blue flame. By careful regulation of the oxidation glyceric acid and tartronic acid may be formed. These acids have been shown to have the structures represented by the formulas given below:



The change in each case consists in the conversion of a primary alcohol group into carboxyl, the group characteristic of acids. These transformations are further evidence of the correctness of the structure assigned to glycerol.

101. *Nitroglycerin.*—Nitric acid converts glycerol into a mononitrate, $C_3H_5(OH)_2NO_3$, and a trinitrate, $C_3H_5(NO_3)_3$. When nitric acid diluted with 3 parts of water is used the mononitrate is formed. The trinitrate, which is usually called *nitroglycerin*, is prepared by dropping glycerin slowly into a mixture of concentrated sulphuric acid and concentrated nitric acid. The mixture is kept at a temperature below 20° by circulating cold brine through coils contained in the "nitrator," the vessel in which the operation is carried out. As much as 3,000 pounds of nitroglycerin are made in a single operation. The sulphuric acid is used as a dehydrating agent. It unites with the water formed in the reaction, and thus prevents the dilution of the nitric acid. When the reaction is complete the mixture is poured into water, and the nitroglycerin which separates is washed with water and finally with a solution of sodium carbonate to remove the acids.

Nitroglycerin is a heavy, colorless, oily liquid, which has a sweet taste and, as ordinarily prepared, a pale-yellow color. It melts at 2.9°, has the density 1.601 at 15°, and explodes when heated to 180°. Small quantities burn in the open air without explosion. Nitroglycerin is very sensitive to shocks, and can readily be exploded by a sharp blow. It is a powerful poison, resembling strychnine somewhat in its physiological effects. It is used as a remedy in heart disease, and is injected into the blood in cases of poisoning by carbon monoxide or water gas.

The chief use of nitroglycerin is as an explosive. Nobel, a Swedish engineer, discovered in 1866 that if nitroglycerin were absorbed in a porous earthy material, such as kieselguhr, it could be transported without danger of premature explosions. This invention of a safe and powerful explosive, which was called *dynamite*, had a marked effect on the material progress of the world, because it solved many engineering difficulties in the construction of roads, railroads, canals, and deep channels in rivers, and in the development of mineral resources.

Dynamite.—In modern dynamite, kieselguhr is replaced by organic absorbents such as wood pulp, flour, starch, or sawdust; the addition of sodium nitrate or ammonium nitrate furnishes oxygen to assist in the combustion of these materials. A dynamite commonly used contains 15 per cent of wood pulp, 33 per cent nitroglycerin, and 52 per cent of sodium or ammonium nitrate. The materials, after thorough mixing, are packed in paper shells covered with paraffin, which prevents the nitroglycerin from being absorbed and also the absorption of water from the air. The addition to the dynamite of a small amount of nitrocellulose, which is a compound prepared by the treatment of cotton or other forms of cellulose with nitric acid, converts the mixture into a jelly-like mass which is impervious to water. Products prepared in this way are called gelatin dynamite and blasting gelatin. The smokeless powder called *cordite* is a mixture of nitroglycerin, nitrocellulose, vaseline, and acetone. This has been used for a number of years as ammunition by the English. The American smokeless powder does not contain nitroglycerin.

Higher Polyhydroxy Alcohols

102. Alcohols are known which contain four, five, six, and seven hydroxyl groups. Some of these occur in nature and some have been made synthetically. *Erythritol* has the structure represented by the formula $CH_2OH.CHOH.CHOH.CH_2OH$. *Adonitol*, *xylitol*, and *arabitol* are alcohols which contain five hydroxyl groups. They all have the structure $CH_2OH(CHOH)_3CH_2OH$. Examples of alcohols containing six hydroxyl groups are *mannitol*, *dulcitol*, and *sorbitol*. These alcohols occur in nature in the sap of certain trees. Sorbitol is also found in the berries of the mountain ash and in many fruits. Alcohols of this class may be made in the laboratory by the reduction of certain sugars. These reactions will be discussed when the carbohydrates are considered.

The names formerly given to these higher polyhydroxy alcohols ended in the syllable *ite:* sorbitol was called sorbite; mannitol, mannite; etc.

Problems

1. Write equations for reactions by which allyl alcohol can be prepared from (*a*) $CH_2I.CHI.CH_2OH$; (*b*) $CH_2OH.CHOH.CH_2OH$; (*c*) $CH_2Br.CHBr.CH_2Br$.

2. By what reactions could (*a*) glycerol be prepared from allyl alcohol, (*b*) normal propyl alcohol from glycerol?

3. Knowing the molecular formula of allyl alcohol, C_3H_6O, how could you show by the quantitative analysis of compounds prepared from the alcohol that it contains one double bond and one alcoholic hydroxyl group?

4. How could you show that glycerol contains three hydroxyl groups?

5. If you were given unlabeled samples said to be the following substances, by what chemical tests would you be able to identify each? (*a*) Propyl alcohol, (*b*) allyl alcohol, (*c*) propargyl alcohol, (*d*) hexane, (*e*) hexene.

6. By what simple physical test other than boiling point could you distinguish the following: (*a*) allyl alcohol and isoamyl alcohol, (*b*) glycerol and nonane, (*c*) isoamyl alcohol and hexane?

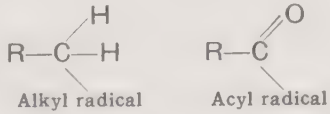
7. Write equations for reactions by which may be prepared: (*a*) propylene glycol, $CH_3.CHOH.CH_2OH$, from propylene; (*b*) butylene glycol, $CH_3.CH_2.CHOH.CH_2OH$, from butyl alcohol.

8. What substances would yield on oxidation the following acids: (*a*) $CH_2OH.CHOH.COOH$, (*b*) $CH_3.CHOH.COOH$, (*c*) $COOH.CHOH.CHOH.COOH$?

CHAPTER VII

MONOBASIC ACIDS

103. In the last two chapters the important class of organic compounds known as alcohols was described. The characteristic chemical properties of these compounds are due to the fact that they all contain a hydroxyl group. Many compounds of importance are known which contain this group, but which differ markedly from the alcohols in their chemical behavior with other substances. These substances can be separated into well-defined classes. The members of one of these classes are known as acids. It has been pointed out that the reactions of a group of atoms, such as the hydroxyl group, are largely determined by the nature of the radical with which the group is in combination. The fact is well shown in the case of alcohols and acids. The radicals which are present in alcohols contain carbon and hydrogen; those present in acids contain oxygen in addition to these two elements. Ethyl alcohol, $CH_3CH_2.OH$, is a typical alcohol; acetic acid, $CH_3CO.OH$, is a typical acid. The relation between the two kinds of groups is shown by the following formulas:



The letter R represents any alkyl radical. As the radicals present in acids occur in many compounds they have been given the general name *acyl*.[1] The specific name for any acyl radical is derived from the name of the acid in which it occurs. Thus, acetic acid, $CH_3CO.OH$, contains the acetyl radical, CH_3CO; propionic acid, $C_2H_5CO.OH$, the propionyl radical, C_2H_5CO; and butyric acid, $C_3H_7CO.OH$, the butyryl radical, C_3H_7CO. A primary

[1] Acyl radicals should not be confused with the acid radicals which exist as ions; CH_3CO is the acyl radical of acetic acid, whereas CH_3COO- is the negative ion of this acid.

alcohol, as has been shown, contains the group CH_2OH, and an acid contains the group COOH. The latter is called the *carboxyl group.* Such acids are thus carboxyl derivatives of the hydrocarbons. Those which contain one such group and are derived from the hydrocarbons of the methane series are called *fatty acids.* This name was given to these acids as many of them were first obtained as the result of the decomposition of fats.

Many organic acids occur in nature, either free or in the form of inorganic salts or of esters. They are formed in growing plants and as the result of the fermentation of the sugars which occur in fruits. They occur as glycerol esters in fats and oils. From tallow, butter, olive oil, etc., can be obtained a large number of acids by heating with steam; the glycerol esters are hydrolyzed and the acids are set free.

When arranged according to their chemical composition the fatty acids form a homologous series. The first member in the series has the composition represented by the formula CH_2O_2. It is known as formic acid. As it contains the carboxyl group its structural formula is H.COOH. The second member in the series is acetic acid, CH_3.COOH; the third propionic acid, C_2H_5.-COOH; etc. A few of the more important acids will be considered in some detail.

104. Formic Acid, H.COOH.—Formic acid (from Latin, *formica,* ant) occurs in nettles, bees, and ants. The irritation produced as a result of the sting of most insects is apparently due to the presence of formic acid in the liquid which is injected into the skin. Formic acid is a colorless, mobile, hygroscopic liquid. When pure, it melts at 8.4°, boils at 100.5°, and has the specific gravity 1.220 at $\frac{20°}{4°}$. It causes painful blisters when left in contact with the skin. The acid has a pungent, irritating odor resembling that of sulphur dioxide. Formic acid cannot be separated from water by fractional distillation as it forms a constant-boiling mixture with water. The mixture boils at 107.1°, and contains 77.5 per cent of formic acid.

Preparation.—Formic acid may be obtained by the direct oxidation of methyl alcohol. Sodium formate is prepared industrially by heating sodium hydroxide at 210° with carbon monoxide under a pressure of 8 atmospheres:

$$CO + NaOH = H.COONa$$

Formic acid is usually prepared in the laboratory by distilling a mixture of oxalic acid and glycerol; as the final result of the reaction, the acid is converted into carbon dioxide and formic acid:

$$(COOH)_2 = CO_2 + H.COOH$$

105. A number of reactions take place when glycerol and oxalic acid are heated together. Formic acid is produced when the decomposition takes place at about 120°. It is probable that the changes involved are as follows: Glycerol as an alcohol reacts with oxalic acid and forms an ester, one hydrogen atom of the acid being replaced:

$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} + (COOH)_2 = \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OOC.COOH \end{array} + H_2O$$

When heated to about 120° this acid oxalate loses carbon dioxide and is thereby converted into a formate:

$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OOC.COOH \end{array} = \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OOC.H \end{array} + CO_2$$

On the addition of more oxalic acid to the reaction mixture, formic acid is liberated:

$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OOC.H \end{array} + (COOH)_2 = \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OOC.COOH \end{array} + H.COOH$$

The acid oxalate which results can be made to pass through the change just indicated. The formation of allyl alcohol (**89**) takes place at a higher temperature, 210° to 260°. Under these circumstances a dioxalate is probably formed, which is changed by loss of carbon dioxide into allyl alcohol:

$$\begin{array}{l} CH_2OH \\ | \\ CH\ OOC \\ | \quad | \\ CH_2OOC \end{array} = \begin{array}{l} CH_2OH \\ | \\ CH \\ \| \\ CH_2 \end{array} + 2CO_2$$

106. *Chemical Properties.*—Formic acid and its salts when heated with concentrated sulphuric acid are decomposed, and carbon monoxide is formed. The presence of the latter can be shown by the fact that the gas produced burns with a blue flame.

The acid and its salts are reducing agents. Mercuric chloride, for example, when warmed with the acid is reduced to mercurous chloride:

$$2HgCl_2 + H.COOH = 2HgCl + 2HCl + CO_2$$

When a solution of mercuric formate is heated, it is reduce to mercurous formate, and finally to mercury:

$$2(H.COO)_2Hg = 2H.COOHg + H.COOH + CO_2$$
$$2H.COOHg = 2Hg + H.COOH + CO_2$$

Silver formate undergoes a decomposition similar to tha expressed by the last equation. All the reactions described abov are of value in identifying a formate.

107. Acetic Acid, $CH_3.COOH$.—Acetic acid occurs as este in the odoriferous oils of many plants, and in fruit juices whic have become sour as the result of fermentation. It is the chie acidic constituent of vinegar. Pure anhydrous acetic acid is colorless, crystalline, hygroscopic solid, which melts at 16.671 and boils at 118.1°. On account of the fact that the solid resem bles ice in appearance, this form of the acid is called *glacia acetic acid*. The acid blisters the skin and has a penetrating odo and sharp sour taste. At or near its boiling point it burns wit a feebly luminous flame. It is soluble in water, alcohol, an ether in all proportions and is an excellent solvent for mos organic and some inorganic substances which are insoluble o sparingly soluble in water, as for example sulphur and iodine

The specific gravity of acetic acid is 1.049 at $\frac{20°}{4°}$. When wate is added to the acid, the specific gravity increases to 1.075 when the aqueous solution contains 77 per cent of anhydrou acid. This composition corresponds to the relationship indicate by the formula $CH_3COOH.H_2O$. Further addition of wate results in a decrease in specific gravity. The solution whic contains 43 per cent of acetic acid has the same specific gravity as that of the pure acid.

108. Vinegar.—Acetic acid is prepared industrially by the oxidation o alcohol and by the distillation of wood. By the first method, which is th one used in the manufacture of vinegar, a dilute aqueous solution of the aci is obtained, which contains many substances in small quantities in additio to acetic acid. The oxidation of alcohol to acetic acid can be effected read ily by means of ordinary oxidizing agents. Atmospheric oxygen will conver an aqueous solution of alcohol into acetic acid, in the presence of spongy platinum. Industrially, the change to acetic acid is brought about by mean of certain bacteria which are present in the air. The micro-organism, *Myco derma acti*, which is presented in "mother of vinegar," is the chief agen involved in bringing about the change. A pure aqueous solution of alcoho

will not ferment. The bacteria multiply and exercise their functions only in the presence of air, and when supplied with a soluble phosphate and with organic compounds which contain nitrogen. Such substances are present in the juices of fruits, and, consequently, when cider is left exposed to the air, fermentation takes place and the liquid becomes sour as the result of the formation of acetic acid. Vinegar is prepared in this way from cider, wine, and dilute solutions of alcohol which have been made by the fermentation of malt. The process requires several weeks for completion, as the oxygen required for the transformation is taken up only at the surface of the liquid. The vinegar prepared in this way contains from 6 to 10 per cent of acetic acid.

The fermentation of malt decoctions or diluted alcohol is generally accomplished by the *quick vinegar process.* In this process a mixture of vinegar and the solution to be fermented is allowed to trickle slowly through tall vats nearly filled with beechwood shavings, which have been previously soaked in vinegar and are covered by the bacteria which bring about the fermentation. The vats are so arranged that a slow current of air passes through them, and care is taken to keep the temperature at as near 30° as possible. In order to increase the amount of acetic acid formed, the solutions are passed through a number of vats in succession. The percentage of acid in the final product varies ordinarily from 4 to 6 per cent. Eight to twelve days are required for the process.

The quality of vinegar is usually determined by the source from which it is prepared. While its use as a condiment is due to its being an acid, its color, aroma, and flavor are the result of the presence in it of very small quantities of esters and other substances, which vary with the source. The different kinds of vinegar can be distinguished from one another by the determination of the presence in them of substances other than acetic acid. For example, cider vinegar contains malic acid, which is present in apples; wine vinegar contains the tartaric acid and cream of tartar present in the grapes from which it was prepared; and malt vinegar contains dextrin and other substances. Spirit vinegars, so-called, are made from dilute alcohol, and lack much of the odor and flavor of fruit or malt vinegars. They are often colored with caramel and flavored with certain esters which impart to them an odor resembling that of true vinegar.

109. Preparation of Acetic Acid.—Acetic acid is prepared in large quantities by the oxidation of dilute alcohol made from molasses and by the distillation of wood. The latter process was described when methyl alcohol was considered (**61**). The vapor of the distillate from the wood is usually passed into milk of lime, which combines with the acid and forms calcium acetate. The salt obtained by evaporating the solution to dryness is called *gray acetate of lime.* Commercial acetic acid is obtained from the calcium acetate so prepared by distilling with concentrated hydrochloric acid in copper stills. The acid is a slightly

colored liquid which contains about 50 per cent of acetic acid. It may be further purified by redistilling over a little potassium dichromate, which oxidizes some of the impurities, and by filtering through charcoal.

Acetic acid is manufactured from acetaldehyde prepared from acetylene (**53**). When the aldehyde is treated with air under pressure and in the presence of manganese acetate, which serves as a catalyst, acetic acid is formed. The transformations are represented by the following equations:

$$C_2H_2 + H_2O = CH_3.CHO;\ 2CH_3.CHO + O_2 = 2CH_3.COOH$$

In the preparation of the anhydrous acid a mixture of anhydrous sodium acetate and concentrated sulphuric acid is distilled. The acetate is purified either by recrystallization or by fusion to destroy the tarry matter present. Acetic acid can be freed from water by repeated distillation, as it does not form a constant-boiling mixture with water. To obtain a very pure glacial acid, a sample of acetic acid which contains a small amount of water is frozen and then allowed to melt partially. As much of the liquid as possible is poured off, and what is left is melted and frozen again. This is partially melted and the process repeated. The glacial acid can also be conveniently prepared by first determining the amount of water present in a sample of acid by an observation of the freezing point, then adding the calculated amount of acetic anhydride (**151**) to unite with the water present to form acetic acid and boiling the mixture for some time. One per cent of water in acetic acid causes a depression of 2.16° in the freezing point.

110. Uses of Acetic Acid.—Acetic acid is used in the manufacture of "white lead." When lead is exposed to the vapor of acetic acid, lead acetate is formed, which is converted into a basic carbonate by carbon dioxide and water vapor. Many salts of acetic acid are known and a number are used extensively. *Sodium acetate*, $CH_3COONa.3H_2O$, crystallizes well. When heated, it first melts and then solidifies when the water of crystallization has been driven off. With increase in temperature the anhydrous salt melts and finally decomposes with the formation of sodium carbonate. *Potassium acetate* is an anhydrous salt. Lead acetate, called *sugar of lead*, $(CH_3COO)_2Pb.3H_2O$, is prepared by dissolving litharge in acetic acid; when an excess of the oxide is used basic salts are formed. One of these, which apparently has the formula $Pb\begin{matrix}OH\\ \\OOCCH_3\end{matrix}$ is used to clarify sugar solutions

before they are analyzed. *Verdigris* is a basic acetate of copper which corresponds in composition closely to that represented by the formula $Cu(OH)_2.(CH_3COO)_2Cu$. It is used as a green pigment. *Paris green* is a double salt which contains copper acetate and copper arsenite. One of the formulas assigned to it is $(CH_3COO)_2Cu.Cu_3As_2O_6$. It is prepared by adding a thin paste of verdigris in water to a boiling solution of arsenous acid which contains acetic acid. It is chiefly used to exterminate potato beetles and other insects. Small quantities of the compound find application as a pigment. The acetates of iron, aluminium, and chromium are extensively used as mordants in dyeing and in calico printing. When an aqueous solution of the neutral acetate of iron, chromium, or aluminium which contains a small quantity of other salts is heated, the acetate is decomposed and a basic salt is precipitated. This fact is made use of in quantitative analysis in separating the trivalent from other metals, for example, in the separation of iron from manganese.

111. Syntheses of Acetic Acid.—Acetic acid may be prepared from simple substances by methods which throw light on its structure. As these methods are examples of general synthetical processes used to prepare organic acids they are of prime importance.

Oxidation of Alcohol.—Acetic acid may be prepared by heating alcohol with a solution of chromic acid, potassium permanganate, or other strong oxidizing agents. The reaction consists in converting the group in alcohol which is characteristic of a primary alcohol into a carboxyl group:

$$CH_3.CH_2OH + 2O = CH_3.COOH + H_2O$$

As all alcohols which contain the group CH_2OH undergo this change, the reaction should be carefully noted. The manner in which this takes place has been discussed in connection with the oxidation of alcohols (**74**) when the intermediate formation of acetaldehyde was assumed.

112. *Hydrolysis of a Cyanide.*—A second and equally important method of preparing an acid is illustrated in the case of acetic acid by the following equation:

$$CH_3.CN + 2H_2O = CH_3.COOH + NH_3$$

Acetic acid and ammonia, which react and form ammonium acetate, are produced. Methyl cyanide is a volatile liquid which may be prepared by heating methyl iodide with potassium cyanide:

$$CH_3I + KCN = CH_3.CN + KI$$

When methyl cyanide is heated with water, a reaction take place according to the equation written above. The chang takes place more rapidly in the presence of an alkali or an acid either of which serves to catalyze the reaction. The chang which takes place is one of hydrolysis, as the cyanide react with water and is converted into two other compounds. Thi method of preparing an acid is a general one, as all alkyl cya nides (ethyl cyanide, butyl cyanide, etc.) are hydrolyzed when boiled with an aqueous solution of an acid or base. The cya nides are frequently called *nitriles*. Methyl cyanide is called acetonitrile, on account of its relation to acetic acid. The cyanides will be discussed at length later (**248**).

113. The reaction between a cyanide and water is brought about as the result of the separation of nitrogen from carbon in the CN radical; it can be formulated as follows:

$$CH_3.C\equiv N + \begin{matrix}HOH\\HOH\\HOH\end{matrix} = CH_3.C\begin{matrix}OH\\OH\\OH\end{matrix} + N\begin{matrix}H\\H\\H\end{matrix}$$

The compound with the formula $CH_3.C(OH)_3$ then loses water and acetic acid is formed: $CH_3C(OH)_3 = CH_3COOH + H_2O$. It is probable that the so-called orthoacetic acid, $CH_3.C(OH)_3$, exists in solution; when an attempt is made to isolate it, it passes into acetic acid. There is some evidence for this view in addition to the change in the density of acetic acid when diluted with water (**107**). Esters of the ortho acid have been prepared; the ethyl ester has the composition represented by the formula $CH_3.C(OC_2H_5)_3$. Esters of a similar structure can be obtained from other acids. The hypothetical form of the acids from which they are derived are called ortho acids. Orthocarbonic acid has the formula $C(OH)_4$, orthoformic acid, $H.C(OH)_3$, etc.

By the Grignard Reaction.—When magnesium alkyl halides are treated with carbon dioxide, the gas is absorbed and an addition product is formed, which is converted by water into an acid. The reactions in the case of the preparation of acetic acid are expressed by the following equations:

$$CH_3I + Mg = CH_3—Mg—I$$
$$CH_3—Mg—I + CO_2 = CH_3CO_2—Mg—I$$
$$CH_3CO_2—Mg—I + HOH = CH_3CO_2H + HO—Mg—I$$

The salts of acetic acid and its homologues can be prepared by a reaction that resembles closely that by which sodium formate

is prepared by the action of carbon monoxide on sodium hydroxide. When the gas is passed over heated sodium methylate, sodium acetate is formed. The equations written to express the similarity in the two reactions are as follows:

$$HONa + CO = HCOONa$$
$$CH_3ONa + CO = CH_3COONa$$

114. Reactions of Acetic Acid.—Acetic acid shows the properties which are characteristic of acids. It decomposes carbonates, forms salts with metallic hydroxides, and reacts with iron, zinc, and other metals. Acetic acid forms esters with alcohols. In order to increase the yield of the ester and the rate of the reaction, a dehydrating agent is usually added to the mixture of alcohol and acid. Ethyl acetate is prepared by warming a mixture of glacial acetic acid, alcohol, and sulphuric acid:

$$CH_3.COOH + C_2H_5OH = CH_3.COOC_2H_5 + H_2O$$

Acetic acid resists to a high degree the action of oxidizing agents. Its stability under these circumstances is so great that it is often used as a solvent for substances which are to be oxidized by chromic acid.

When chlorine is passed into boiling acetic acid, preferably in the sunlight, the hydrogen atoms in the methyl group are, one after another, replaced by chlorine. In this way may be obtained compounds which have the formulas $CH_2Cl.COOH$, $CHCl_2.COOH$, and $CCl_3.COOH$. They are called chloroacetic acid, dichloroacetic acid, and trichloroacetic acid, respectively. The replacement of hydrogen by chlorine in this case is an example of a general reaction. In order to replace by chlorine a hydrogen atom which is joined directly to carbon, the free halogen is used. In order to increase the rate at which the substitution takes place, a catalyst such as sulphur or iodine may be used.

The chlorides of phosphorus replace the hydroxyl group in acetic acid by chlorine. The replacement is an example of a general reaction which has been mentioned in connection with the alcohols. The equation for the reaction in the case of phosphorus trichloride is as follows:

$$3CH_3CO.OH + PCl_3 = 3CH_3CO.Cl + P(OH)_3$$

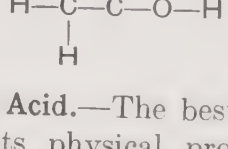
115. Structure of Acetic Acid.—The chemical behavior of acetic acid, which has been described, leads to the structure

that has been assigned to it. One hydrogen atom in the molecule differs from the rest of those present in that it can be replaced by metals: $C_2H_4O_2$ when treated with sodium gives $C_2H_3O_2Na$. The reaction between acetic acid and phosphorus trichloride shows that the compound contains a hydroxyl group. When the acid is warmed with phosphorus trichloride one oxygen atom and one hydrogen atom are replaced by one chlorine atom. As the valence of the halogen is 1, it is clear that the valence of the group of atoms which it replaced must also be unity. An oxygen and a hydrogen atom combined can show a valence of 1 only when they are in combination as a hydroxyl group.

The above considerations lead to the conclusion that the formula of acetic acid may be written $C_2H_3O.OH$. The synthesis of the acid, indicated by the following formulas, shows that it contains a methyl radical:

$$CH_4 \longrightarrow CH_3.Br \longrightarrow CH_3.CN \longrightarrow CH_3.COOH$$

Methyl cyanide is converted into acetic acid by the action of water, which does not affect a methyl group. If acetic acid contains a hydroxyl group and a methyl radical, the only possible structure is the following:



116. Tests for Acetic Acid.—The best way to identify acetic acid is to determine its physical properties—melting point, boiling point, odor—and those of a derivative prepared from it, such as the ethyl ester. If, however, only a small amount of the acid to be tested is available, or if it is in solution in water or mixed with other substances, it can be satisfactorily identified. As acetic acid is volatile with steam, it can be freed by distillation from substances nonvolatile under these circumstances. The original solution should be acidified with sulphuric acid before distillation, in order to set free any acetic acid which may be present in the form of a salt. The distillate is neutralized with sodium hydroxide and evaporated to dryness. A part of the residue is treated with a few drops of concentrated sulphuric acid and gently heated. If acetic acid is present it can be recognized by

its characteristic odor. A second portion of the residue is mixed with a few drops of alcohol and an equal quantity of concentrated sulphuric acid and warmed. The presence of the acid is confirmed by the odor of ethyl acetate, which is readily recognized.

Higher Fatty Acids

117. The known fatty acids form a complete homologous series up to the compound which contains 20 carbon atoms. The acid in this series containing the largest number of carbon atoms has the formula $C_{33}H_{67}COOH$. The acids may be considered as derivatives of the paraffin hydrocarbons in which a hydrogen atom is replaced by a carboxyl group.

It will be recalled that propane yields two substitution products. The formulas of the two propyl bromides are

$$CH_3.CH_2.CH_2Br \quad \text{and} \quad CH_3.CHBr.CH_3.$$

The replacement of the halogen atom in these compounds by the CN radical and the subsequent hydrolysis of the nitriles so prepared should yield acids of the structure

$$CH_3.CH_2.CH_2.COOH \quad \text{and} \quad \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CH.COOH.$$

Two fatty acids each of which contains four carbon atoms are known. Their synthesis and reactions are in accord with the view that they have the structure represented by the formulas given above. The acid in which the carbon atoms are in a straight chain is called butyric acid; the isomeric acid is known as isobutyric acid. The opportunity for isomerism among the acids is as great as in the case of the hydrocarbons, but only a small number of the possible isomers have been prepared. A table of a few of the normal acids—those in which the carbon atoms are united in a straight chain—follows on page 126.

It will be seen from the table that the acids up to capric acid, which contains 10 carbon atoms, are liquids at ordinary temperatures. The higher members in the series are waxy solids, which boil without decomposition only under reduced pressure. An interesting fact which has not been explained is that, while the boiling points of the acids increase with a fair degree of regularity as the number of carbon atoms increases, the melting

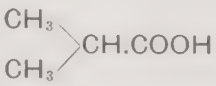
points show a peculiar irregularity. The melting points of the acids which contain an even number of carbon atoms are higher than those of the acids which contain an odd number of carbon atoms and which immediately precede or follow them in the series. The solubility in water of the acids and their volatility with steam decrease with the number of carbon atoms in the molecule. This difference in solubility and volatility of the acids is the basis of two important analytical methods which are used in the examination of fats (**173**). The lower members in the series have characteristic odors, those containing from 4 to 9 carbon atoms having a disagreeable smell, resembling that of rancid butter. The fatty acids are weak acids, *i.e.*, they are but slightly ionized in solution.

NORMAL FATTY ACIDS, $C_nH_{2n}O_2$

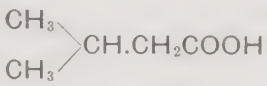
Name	Radical in combination with COOH	Melting point, °C.	Boiling point at 760 mm. °C.	Density, $\frac{20°}{4°}$
Formic	H	8.4	100.5	1.220
Acetic	CH_3	16.6	118.1	1.049
Propionic	C_2H_5	−22.0	141.1	0.992
Butyric	C_3H_7	− 7.9	163.5	0.959
Valeric	C_4H_9	−59	187.0	0.942
Caproic	C_5H_{11}	− 9.5	202	0.929
Heptylic (enanthic)	C_6H_{13}	−10	223.5	0.922
Caprylic	C_7H_{15}	16	237.5	0.910
Pelargonic	C_8H_{17}	12	254	0.907
Capric	C_9H_{19}	31	268.4	0.895 (m.p.)
Palmitic	$C_{15}H_{31}$	64	215 $^{15mm.}$	0.853 (m.p.)
Margaric	$C_{16}H_{33}$	59.9	227 $^{100mm.}$	0.853 (m.p.)
Stearic	$C_{17}H_{35}$	69.3	383	0.847 (m.p.)

The fatty acids of high molecular weight which are used commercially are obtained from animal and vegetable fats and oils. Recent attempts to prepare these acids from petroleum have been successful. When hydrocarbons which boil at a high temperature are heated with air in the presence of mercuric oxide, they are converted into acids. The process may prove of industrial significance.

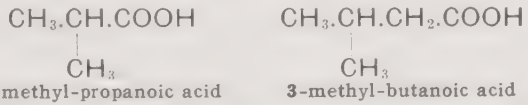
118. Nomenclature of Fatty Acids.—Acids are frequently named as substitution products of acetic acid. Thus the acid of the structure



is called, for example, dimethyl-acetic acid;



is isopropyl-acetic acid. According to the Geneva system the name of the acid is derived from the name of the hydrocarbon containing the same number of carbon atoms by replacing the final *e* by the termination *oic*. Thus, acetic acid is called ethanoic acid. When side chains are present the acid is considered as a substitution product of a straight-chain acid. The method will be clear from the following examples:



119. Propionic Acid, $C_2H_5.COOH$.—This acid occurs in small quantities in pyroligneous acid. It can be prepared by the application of the general synthetical methods described under acetic acid. It resembles the latter in chemical properties. When propionic acid is treated with chlorine, substitution takes place, the compound formed having the structure $CH_3.CHCl.COOH$. This is called α-chloropropionic acid to distinguish it from an isomer, called β-chloropropionic acid, in which the halogen atom is united to the end carbon atom of the chain, $CH_2Cl.CH_2.COOH$. In naming substitution products of the fatty acids there is prefixed to the name a Greek letter which serves to indicate the carbon atom with which the substituent is in combination. The first, second, third, fourth, etc., carbon atom from the carboxyl group are designated by α, β, γ, δ, etc., respectively.

120. Butyric Acids, $C_3H_7.COOH$.—Two acids of the formula $C_4H_8O_2$ are known. In normal butyric acid the propyl radical is in combination with the carboxyl group, $CH_3CH_2CH_2.COOH$;

isobutyric acid contains the isopropyl radical, $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH.COOH$

The structures of the acids are derived from their syntheses from propyl bromide and isopropyl bromide respectively. Normal butyric acids occur in combination with glycerol in butter (whence the name of the acid), and in other fats. It is formed as the result of the fermentation of sugars, fats, and other substances and is found in the free state in rancid butter, Limburger cheese and sweat. It has a characteristic, disagreeable odor. It can be prepared by the general synthetic methods which have been described. A micro-organism which appears to be present in Limburger cheese has the power to convert lactic acid, the chief acid constituent of sour milk, into butyric acid. The acid is conveniently prepared in this way.

Butyric acid is a thick sour liquid, which boils at 163.5° and is miscible with water in all proportions. Addition of calcium chloride to an aqueous solution of the acid causes the latter to separate as an oil. The other soluble fatty acids, with the exception of formic and acetic acids, act in this way. The salts of butyric acid are soluble in water. Calcium butyrate, $(C_4H_7O_2)_2Ca.H_2O$, is more soluble in cold than in hot water. It is precipitated, in part, when a cold saturated solution of the salt is heated to boiling. The calcium salt of isobutyric acid, $(C_4H_7O_2)_2Ca.5H_2O$, is more soluble in hot than in cold water.

121. Valeric Acids, $C_4H_9.COOH$.—The four possible acids of the formula $C_5H_{10}O_2$ are known. Isovaleric acid, $(CH_3)_2CH$-CH_2COOH, and active valeric acid, $\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>\!CH.COOH$, occur in nature. They are found in the plant all-heal or valerian, and in angelica root. A mixture of these acids may be prepared by oxidizing commercial amyl alcohol with chromic acid.

122. Palmitic acid, $C_{15}H_{31}.COOH$, **and stearic acid,** $C_{17}H_{35}$-$COOH$, occur as glycerol esters in most animal and vegetable fats and oils. They are prepared from these sources in large quantities for the manufacture of stearin candles, tallow and palm oil being chiefly used. The hydrolysis of the fat is usually accomplished by boiling with milk of lime, either in an open

vessel or under a pressure of from 8 to 10 atmospheres. The insoluble calcium salts of the acids so formed are treated with sulphuric acid, when the free fatty acids rise to the surface of the hot solution in the form of an oil. This is allowed to stand for a few days at a temperature of about 30° in order to bring about the crystallization of the palmitic and stearic acids. The oleic acid—an unsaturated acid of the formula $C_{17}H_{33}.COOH$—which is present in the mixture in the form of an oil, is removed by hydraulic pressure. The resulting solid mixture of stearic and palmitic acids is known in the trade as *stearin*. This use of the word should not be confounded with its ordinary use in organic chemistry; palmitin and stearin are the names given to the glycerol esters of palmitic and stearic acids respectively. The yield of *stearin* from tallow or palm oil varies from 44 to 48 per cent of the weight of the fat. The stearin is finally mixed with a small amount of paraffin wax to prevent crystallization, and moulded into candles. Candles are also made from tallow, paraffin, ozokerite, and spermaceti.

123. An improved method of obtaining the acids from fats was developed by Twitchell and is known by his name. It consists in hydrolyzing the fat by heating it with live steam in the presence of very dilute sulphuric acid and the "Twitchell reagent," which serves to emulsify the fat and present a large surface of the latter to the action of water. Different reagents have been used; they are all acids of large molecular weight which are soluble to some extent both in the fat and in water. The one first proposed was a sulphonic acid derived from the phenyl ester of stearic acid, $C_{17}H_{35}$-$COOC_6H_4.SO_3H$. The marked emulsifying effect produced by substances of this type is perhaps due to the fact that the part of the molecule containing the stearic acid radical dissolves in the fat, which it resembles in structure, and the sulphonic acid radical being related to sulphuric acid stays in solution in the water. This peculiar condition affects the surface tension between the water and fat, and minute globules of the latter are formed. The process is frequently used in soap making (**125**).

124. Palmitic acid and stearic acid are colorless, waxlike substances, which melt at 64° and 69.3° respectively. They are insoluble in water but dissolve in organic solvents. The sodium and potassium salts of the acids are soluble in water, while those of calcium, magnesium, and the heavy metals are insoluble. Both acids have the normal structure, *i.e.*, the alkyl radicals

which they contain, $C_{15}H_{31}$ and $C_{17}H_{35}$ respectively, consist o carbon atoms united in a straight chain.

125. Soaps.—Most fats and oils consist of mixtures of glycerides, which are substances that yield glycerol and fatty acids when hydrolyzed. If the hydrolysis is effected by treating the esters with a base, a mixture of the corresponding salts of the acids is obtained. These mixtures are known as soaps. The decomposition of stearin by sodium hydroxide is represented by the following equation, which is typical of the reaction that takes place in the case of the other esters present in fats and oils:

$$(C_{17}H_{35}COO)_3C_3H_5 + 3NaOH = 3C_{17}H_{35}COONa + C_3H_5(OH)_3$$

The decomposition by which a fat is converted into a soap is called *saponification*. The word is frequently applied to the analogous change which esters other than fats undergo with bases, although the salts formed are not soaps. It is sometimes used as synonymous with hydrolysis.

The materials used in soap making vary with the quality of the soap desired. White soaps are usually made from tallow, palm-nut oil, or coconut oil, and common laundry soaps from tallow, bone grease, or cottonseed oil. The fats, such as tallow, that contain practically only the acids of high molecular weight give soaps which are very slightly soluble in water and do not lather well. For this reason an oil is added which is richer in acids of low molecular weight. Rosin is often mixed with the fat in the preparation of the laundry soaps, as it is cheap and yields a soap which lathers freely. Sodium carbonate is usually added to rosin soaps to give them greater firmness and to improve their action as a cleansing agent. Olive oil is used in the manufacture of Castile soap. The so-called *olein soaps* are prepared from the oleic acid obtained as a by-product in the manufacture of stearin candles.

Soaps are usually made by boiling the fat with a solution of sodium hydroxide. After saponification is complete, sodium chloride is added to precipitate the soap which is in solution and the mixture is allowed to separate and settle. The lye, which contains most of the glycerol, is now drawn off, a small amount of water is added, and the soap is boiled or pitched until it takes on a nearly smooth appearance. After settling for about a week the upper two-thirds of the material, which contains about 30 per cent of water, is pumped off into a machine called a "crutcher" and mixed with whatever material is to be incorporated into the soap—sodium carbonate, sodium silicate, borax, sand, or perfume. The warm material is run into frames, allowed to cool, and cut the next day into cakes of the proper size. After drying, the cakes are pressed. Soap made in this way contains about 29 per cent of water when finished. In the preparation of toilet and certain other soaps the material containing about 30 per cent of water is dried until the moisture content is reduced to from 10 to 12 per cent. This is accomplished by allowing the warm soap to run onto an endless belt which passes through a heated chamber, or by allowing it to cool, and then converting it into chips, which are dried. The soap is then mixed with the material

required to give the desired perfume, color, etc., and "milled" by passing through rollers. The material is then compressed into cakes.

Soaps are colored by adding to them small amounts of copperas, ultramarine, or other pigment. *Transparent soaps* are made by dissolving a common soap in alcohol and distilling off the latter from the decanted solution until the residue is obtained as a clear transparent jelly, which is finally carefully dried in moulds. The addition of glycerin and alcohol or a solution of cane sugar to cold-process soaps, renders them more or less transparent.

Hard soaps consist essentially of the sodium salts of palmitic, stearic, and oleic acids. As the calcium and magnesium salts of these acids are insoluble in water, soap does not immediately pass into solution and form a lather with "hard" water. The soap dissolved reacts with the metallic salts in solution and the corresponding salts of the fatty acids are precipitated. This process continues until all the metals which form insoluble soaps are precipitated. The reaction which takes place is illustrated by that between sodium palmitate and calcium chloride:

$$2C_{15}H_{31}.COONa + CaCl_2 = (C_{15}H_{31}.COO)_2Ca + 2NaCl$$

The amount of a solution of soap of definite concentration which must be added to a definite volume of water before the mixture produces a lather on shaking is taken as a measure of the hardness of water in water analysis.

If an oil is shaken with a solution of soap, the former is converted into a colloidal condition, *i.e.*, it becomes so finely divided that it remains suspended in the liquid. This result is, in part, due to the fact that the soap is hydrolyzed to a slight degree, and free sodium hydroxide is present in the solution. It is this behavior of fats and oils with soap that makes the latter an excellent cleansing agent.

126. Properties of Acids of Analytical Significance.—The identification of the acids of this series is not difficult when an individual in the pure state is to be identified. In general, however, the acids are found mixed with other substances and their separation in a pure condition is difficult. The physical properties of the acids, which have been described at some length, are helpful in their determination. The odor and solubility of the lower members of the series, the fact that calcium chloride precipitates most of the soluble acids, and the waxy appearance of the higher members should be noted. Being saturated compounds they do not readily react with the halogens. They dissolve in sodium hydroxide and sodium carbonate. The salts of the higher acids are hydrolyzed by water. The sodium salts of the higher acids are soaps and show the characteristic lathering when agitated with water.

Unsaturated Monobasic Acids

127. A number of acids are known which stand in the same relation to the unsaturated hydrocarbons as do the fatty acids to the paraffins. Some of these acids occur in nature in the free condition or in the form of esters, and others have been synthesized in the laboratory. Those which occur in nature have names that recall the names of the substances from which they were first prepared; crotonic acid, for example, was isolated from croton oil.

It will be recalled that a double bond can be established in a compound by the removal of a molecule of halogen hydride (HCl, HBr, or HI) or two halogen atoms from a halogen derivative of a saturated hydrocarbon, and by the elimination of water from an alcohol. The substitution products of the fatty acids undergo analogous changes when subjected to the action of the proper reagents. The presence of the carboxyl group modifies, to some extent, the ease with which a double or triple bond is established, but the course of the reaction is the same as in the case of the simple substitution products of the hydrocarbons.

Nomenclature of Unsaturated Acids.—In the systematic nomenclature of organic compounds the acids of this series are named from the hydrocarbons to which they are related, in a way analogous to that adopted for the fatty acids. For example, acrylic acid, $CH_2{=}CH.COOH$, is named propenoic acid. The position of the double bond is indicated by placing before the name of the acid the Greek letter Δ to which is added a number indicative of the position of the double bond; thus, the substance of the structure, $CH_3.CH_2.CH{=}CHCH_2COOH$ is called Δ^2-hexenoic acid. The $(^2)$ after the Δ indicates that the double bond is between the second and third carbon atom from the carboxyl group. This acid is also named β-hexenic acid. The older names of the acids are usually used; in the case, however, of newly described acids and those of complex structure, the systematic method of naming compounds is employed.

128. Acrylic Acid, $CH_2{=}CH.COOH$.—The synthesis of unsaturated acids may be illustrated by the methods which can be used to prepare acrylic acid—the first member of the series of acids which contain one double bond.

Preparation.—Acrylic acid is formed when β-iodopropionic acid is warmed with an alcoholic solution of potassium hydroxide:

$$CH_2I.CH_2.COOH + 2KOH = CH_2:CH.COOK + KI + 2H_2O$$

The acid formed reacts with a part of the alkali present and is obtained as the potassium salt. It has been found in this and other cases that a halogen atom in the β-position to the carboxyl group is readily removed in this way. α, β-Dibromopropionic acid is converted into acrylic acid when treated with zinc in the presence of dilute sulphuric acid:

$$CH_2Br.CHBr.COOH + Zn = CH_2:CH.COOH + ZnBr_2$$

The preparation of an unsaturated acid by bringing about the elimination of water from a saturated compound is illustrated by the preparation of acrylic acid from the hydroxyl derivatives of propionic acid. When β-hydroxypropionic acid is distilled, decomposition takes place and acrylic acid is formed:

$$CH_2OH.CH_2.COOH = CH_2:CH.COOH + H_2O$$

If the unsaturated acid is not formed as the result of heat alone, the acid is warmed with a dehydrating agent, or a salt of it is heated. Thus, when the sodium salt of lactic acid is heated, the sodium salt of acrylic acid is formed:

$$CH_3.CHOH.COONa = CH_2:CH.COONa + H_2O$$

Acrylic acid may be prepared by two methods analogous to those used in the preparation of fatty acids. Allyl alcohol and acrolein, the corresponding aldehyde, are converted into acrylic acid by oxidation:

$$CH_2:CH.CH_2OH + 2O = CH_2:CH.COOH + H_2O$$

$$CH_2:CH.CHO + O = CH_2:CH.COOH$$

The student should study the above reactions in the light of a knowledge of the methods used to prepare unsaturated hydrocarbons. A review of these methods (**37**) at this time will serve to make the knowledge of these important reactions more definite, and will do away with the necessity of learning as isolated facts the ways by which acrylic acid may be prepared. The general synthetic methods which have been given so far, and many others to be described later, are used repeatedly in the prepara-

tion of organic compounds. Each new fact should be associated, as far as possible, with facts already learned. It is only in this way that the mass of material treated in organic chemistry can be mastered, and the relationships which exist in the science can be appreciated.

Properties.—Acrylic acid is a liquid which has a pungent odor resembling somewhat that of acetic acid. It is miscible with water in all proportions, melts at 12.3°, boils at 141.9°, and has the specific gravity 1.051 at $\frac{20°}{4°}$. It is a stronger acid than acetic acid and forms well-characterized salts and esters. The fact that it contains a double bond is shown by its behavior with other substances. It can be reduced to propionic acid by nascent hydrogen:

$$CH_2:CH.COOH + 2H = CH_3.CH_2.COOH$$

It unites directly with chlorine and bromine:

$$CH_2:CH.COOH + Br_2 = CH_2Br.CHBr.COOH$$

The halogen acids add to acrylic acid at the double bond, forming β-substitution products of propionic acid:

$$CH_2:CH.COOH + HI = CH_2I.CH_2.COOH$$

In the addition, the negative halogen atom unites with the more positive end carbon atom. The presence of the carboxyl group in combination with the α-carbon atom renders the latter more or less negative as compared with the carbon atom in the CH_2 group. Addition to unsaturated compounds takes place, in general, in this way. The negative part of the molecule which unites with the unsaturated compound enters into combination with the more positive of the carbon atoms. Hydrogen and alkyl groups are positive; oxygen, hydroxyl, halogen, and carboxyl groups are negative. The presence of these groups in combination with a carbon atom, affects the properties of the latter in relation to its positive or negative nature.

Like the unsaturated hydrocarbons, acrylic acid is oxidized by a cold, dilute, neutral solution of potassium permanganate. The oxidation takes place at the double bond.

The various syntheses of acrylic acid and the chemical reactions which it undergoes with bases, halogens, halogen acids, etc., have led to the view that the structure of its molecule is

represented by the formula which has been assigned to it. The student should endeavor to understand clearly how these syntheses and reactions lead to the accepted conclusion.

129. Crotonic Acids, $C_3H_5.COOH$.—Three unsaturated acids of the formula $C_3H_5.COOH$ should be capable of existence according to the structure theory. These are:

(1) $CH_2{=}C.CH_3.COOH$

(2) $CH_3.CH{=}CH.COOH$

(3) $CH_2{=}CH.CH_2COOH$

The first of these acids may be considered as derived from acrylic acid, $CH_2{=}CH.COOH$, by the replacement of a hydrogen atom joined to the α-carbon atom by a methyl group. It is called methylacrylic acid. The acid may be prepared by treating bromoisobutyric acid with alcoholic potash:

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CBr.COOH = \begin{matrix} CH_2 \\ CH_3 \end{matrix}\!\!>\!C.COOH + HBr$$

The structure of the acid is deduced from this synthesis and from its chemical reactions.

The acid corresponding to the second formula, in which the methyl group is in combination with the β-carbon atom, is called crotonic acid. Two forms of this exist (see following section). The third is vinylacetic acid which has been prepared from allyl bromide by Grignard's method.

Crotonic acid (*trans*-Δ^1-butenoic acid or α-butenic acid) occurs in croton oil. It is a crystalline, colorless solid, which melts at 72° and boils at 185°. It can be prepared from α- or β-bromobutyric acid or from β-hydroxybutyric acid.

Isocrotonic acid (*cis*-Δ^1-butenoic acid) melts at 14.6° and boils at 171.9°. Crotonic acid is transformed into normal butyric acid when reduced by nascent hydrogen. This fact indicates that the carbon atoms in the compound are arranged in a straight chain:

$$CH_3CH:CH.COOH + 2H = CH_3CH_2CH_2.COOH$$

Isocrotonic acid can also be converted into the same acid. Both acids yield β-iodobutyric acid when treated with hydriodic acid.

130. Geometric Isomerism.—The interest in the crotonic acids centers in the fact that an acid is known, isomeric with crotonic acid, which differs markedly from it in physical properties, but appears to have, as a result of the study of its chemical properties, a structure which is best represented by that given to crotonic acid. As the three formulas given above are the only ones possible for acids containing a double bond and having the composition $C_3H_5.COOH$, and as four well-characterized substances of this composition are known which show the kind of unsaturation represented graphically by the so-called doubly linked carbon atoms, an extension of the structure theory as developed so far is necessary. Isomerism, similar to that shown by crotonic and isocrotonic acids, has been observed in many compounds which contain double bonds.

The theory put forward to explain these facts by van't Hoff is an extension of the conception of the space relations of the atoms in the molecule, which has proven so valuable in the study of the isomerism which exists among optically active compounds (**81**).

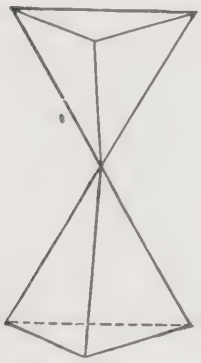


FIG. 6.

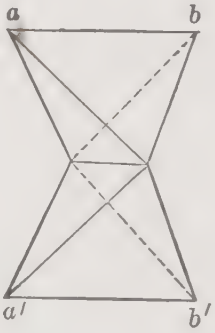


FIG. 7.

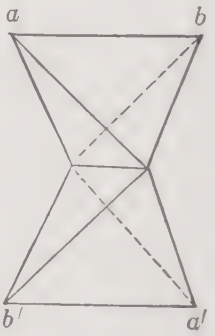
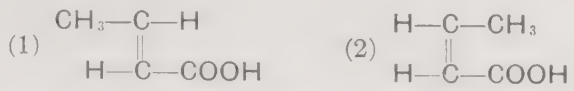


FIG. 8.

The spacial formula of a compound in which two carbon atoms are joined by a single bond is represented by Fig. 6. Figures 7 and 8 represent compounds that contain a double bond. An examination of Figs. 7 and 8 shows that isomerism may exist when the atoms or groups at a and a' are different from those at b and b'. In one case, Fig. 7, a and a' are on the same side of the molecule; in the other case, Fig. 8, they are on opposite sides. The space relations are usually represented on a plane

surface by simple graphic formulas without the use of the tetrahedra, in the following manner:



The compound in which the radicals are on the same side of the molecule are designated by prefixing to the name of the compound the syllable *cis*, which means "on this side." The prefix *trans*, meaning "across," is used in naming the isomer. Formula (1) above is *trans*-crotonic acid; formula (2) *cis*-crotonic acid. The acids are said to be *geometric isomers*.

131. Oleic acid, $C_{17}H_{33}.COOH$, occurs abundantly in nature in combination with glycerol in many fats and oils. Glyceryl trioleate, $(C_{17}H_{33}COO)_3C_3H_5$, is the chief constituent of the fatty oils, such as olive oil and whale oil, and of the fats of cold-blooded animals. It is the liquid constituent of tallow and other animal fats. It is obtained as a by-product in the preparation of stearin candles (**122**) and is used in the manufacture of soap. The acid may be separated from palmitic, stearic, and other acids with which it occurs, by taking advantage of the fact that lead oleate is soluble in ether, in which the lead salts of the other acids are insoluble. Oleic acid is obtained from its lead salt by treatment with an acid. It is an oily, odorless liquid, which is insoluble in water. It solidifies when cooled and forms crystals which melt at 14° and boils at 286° at 100 mm. pressure.

The presence of a double bond in oleic acid is shown by the fact that one gram-molecule of the acid unites with one gram-molecule of bromine; dibromostearic acid is formed:

$$C_{17}H_{33}COOH + Br_2 = C_{17}H_{33}Br_2COOH$$

As nascent hydrogen converts oleic acid into stearic acid, the carbon atoms are arranged in a straight chain. The position of the double bond is indicated by the composition of the products obtained as the result of oxidation:

$$\underset{\text{Oleic acid}}{CH_3(CH_2)_7CH:CH(CH_2)_7COOH} + 4O = \underset{\text{Pelargonic acid}}{CH_3(CH_2)_7COOH} + \underset{\text{Azelaic acid}}{COOH(CH_2)_7COOH}$$

Thus, oleic acid, which contains 18 carbon atoms, is converted by oxidation into two acids, each of which contains 9 carbon atoms. As unsaturated compounds usually break at the double bond when subjected to active oxidation, the reaction given above is taken as evidence that in oleic acid this bond is situated as indicated by the structural formula given. In the oxidation the unsaturated carbon atoms are converted into carboxyl groups; a monobasic acid and a dibasic acid, which contains two carboxyl groups, are thus obtained.

Oleic acid, like other unsaturated compounds, reduces a dilute aqueous solution of potassium permanganate; dihydroxystearic acid is formed:

$$CH_3(CH_2)_7CH:CH(CH_2)_7COOH + O + H_2O = CH_3(CH_2)_7CHOH.CHOH(CH_2)_7COOH$$

Oleic acid undergoes an interesting transformation when treated with a small quantity of nitrous anhydride. In a few minutes it is converted into a solid substance, which appears from its reactions to have a structure identical with that given above for oleic acid. The compound formed, called *elaidic acid*, is a stereoisomer of oleic acid, the relation between the two being similar to that between crotonic and isocrotonic acid. Oleic acid is the *cis* form. The glycerol ester of oleic acid undergoes a similar change and is converted into a solid *elaidin*. This reaction is frequently used in the examination of oils which contain olein. The consistency of the mass after treatment of the oil with a small amount of nitric acid in which mercury or copper has been dissolved, gives some indication of the relative amount of olein in the oil; thus, a hard mass is given by almond, lard, and certain other oils; mustard oil yields a product of the consistency of butter; and a pasty mass which separates from a fluid portion is obtained from cottonseed, sunflower, and sesame oils. The test is known as the *elaidin test*. It is valuable only when used along with other analytical methods.

Acids with Two Double Bonds

132. Sorbic acid, $C_5H_7.COOH$, is an example of acids of this class, very few of which are known. It is present in the unripe berries of the mountain ash. The structure of the acid

has been proved by its synthesis and its reactions to be that represented by the formula $CH_3CH=CH.CH=CH.COOH$. It adds four atoms of bromine or two molecules of hydrobromic acid, and is thereby converted into substitution products of caproic acid, which is a member of the series of saturated acids.

133. Linoleic acid, $C_{17}H_{31}.COOH$, an important acid which contains two double bonds, occurs as the glycerol ester in linseed, cottonseed, sunflower, and other oils. The property, possessed by linseed and other so-called drying oils, of hardening when exposed to the air is due to the fact that the esters of linoleic and similar unsaturated acids absorb oxygen and are thereby converted into solid substances. Such oils are extensively used as constituents of varnishes and oil paints.

The oxidation of linseed oil, which takes place in "drying," is attended by the generation of much heat. If the oil is exposed in thin layers on porous inflammable material such as cotton rags or waste, spontaneous combustion may take place as the result of active oxidation. Linseed oil dries more rapidly when exposed to the air if it has been previously "boiled" for some hours. The process consists in heating the oil with certain oxides or salts, called "driers," such as litharge or borate of manganese, which form compounds that act as catalytic agents in the addition of oxygen to the unsaturated esters. Very little of the drier is dissolved by the oil. Raw linseed oil is used as a soap stock for soft soap, in some kinds of paints, and in the making of varnish and rubber substitutes. Boiled oil is used in paints and in the manufacture of oilcloth and printing ink. Linoleum is made from a mixture of ground cork and boiled linseed oil which has been exposed to the air until oxidized to a translucent jelly.

Linseed oil contains, in addition to the glycerol ester of linoleic acid, the esters of the more highly unsaturated linolenic and isolinolenic acids, both of which have the composition $C_{17}H_{29}.COOH$. The structure of these acids has not been definitely determined.

Acids with One Triple Bond

134. Propiolic acid, $HC\equiv C.COOH$, is a liquid with a pungent odor resembling that of acetic acid. After freezing, it melts at 9°. It can be distilled without decomposition only under diminished pressure. It is interesting on account of the fact that its reactions show clearly its relation to acetylene. It forms, as an acid, well-characterized salts, and, as a triple-bonded compound, metallic derivatives, which result from the replacement by silver or copper of the hydrogen atom joined to carbon.

When the acid is treated with an ammoniacal solution of silver nitrate, a colorless, crystalline salt is formed which soon turns yellow and explodes when struck. Propiolic acid may be prepared by the action of carbon dioxide on the sodium derivative of acetylene:

$$HC{\equiv}CNa + CO_2 = HC{\equiv}C.COONa$$

The free acid is obtained from the salt by treatment with an acid.

Problems

1. Make a summary, by writing equations, of (*a*) the general methods used in preparing acids, and (*b*) the chemical properties of acids, as illustrated in the case of propionic acid.

2. Write equations for reactions by which butyric acid may be prepared from (*a*) butyl alcohol and (*b*) ethyl alcohol; and by which isobutyric may be prepared from (*c*) propyl alcohol.

3. Write the graphic formulas for the acids of the formula $C_5H_{11}COOH$ and name them according to the two systems described in Sec. **118.**

4. By what analytical process could you distinguish silver acetate from silver butyrate?

5. How could you obtain from an aqueous solution which contained alcohol and acetic acid two aqueous solutions, one of which contained only alcohol and the other only acetic acid?

6. How could you separate into its components a mixture of acetic acid and stearic acid?

7. By what reactions can (*a*) a hydrogen atom in an organic compound be replaced by chlorine, (*b*) H by COOH, (*c*) COOH by H, (*d*) H by OH, (*e*) OH by H, (*f*) H by I, (*g*) I by H, (*h*) OH by COOH, (*i*) OH by Br, (*j*) Br by OH?

8. How could you distinguish (*a*) a candle made from paraffin from one made from "stearin," (*b*) a drying oil from a paraffin oil, (*c*) linseed oil from stearin?

9. By what reactions can the following be prepared: (*a*) succinic acid $COOH.CH_2CH_2COOH$, from acrylic acid $CH_2{=}CH.COOH$; (*b*) $HOCH_2.CH_2COOH$ from $CH_2{=}CH.COOH$; (*c*) $CH_3C{\equiv}C.COOH$ from $CH_3C{\equiv}CH$?

10. If an acid is known to contain one carboxyl group how could its molecular weight be determined with the aid of a standardized solution of sodium hydroxide?

CHAPTER VIII

POLYBASIC ACIDS

135. The acids which have been described so far are monobasic acids as they contain only one carboxyl group and therefore but one hydrogen atom which undergoes ionization and can be replaced by metals. A number of acids of importance are known which contain two or more of these groups, and consequently resemble the inorganic acids like sulphuric acid and phosphoric acid in their ability to form acid salts.

The saturated dibasic acids fall into a homologous series having the general formula $C_nH_{2n-2}O_4$. The following table gives a list of some of the dibasic acids which contain the carbon atoms in a straight chain:

DIBASIC ACIDS, $C_nH_{2n-2}O_4$

Name	Formula	Melting point, °C.	Parts by weight soluble in 100 parts of water
Oxalic	COOH.COOH	189.*	9.5† at 20°
Malonic	$COOH.CH_2.COOH$	135.6	153. at 20°
Succinic	$COOH.(CH_2)_2.COOH$	185.	8.35 at 25°
Glutaric	$COOH.(CH_2)_3.COOH$	97.5	83. at 14°
Adipic	$COOH.(CH_2)_4.COOH$	151.	1.44 at 15°
Pimelic	$COOH.(CH_2)_5.COOH$	103.	2.5 at 13.5°
Suberic	$COOH.(CH_2)_6.COOH$	140.	0.14 at 15.5°

* Anhydrous oxalic acid.
† $(COOH)_2.2H_2O$.

It is seen from an inspection of the melting points given in the table that the acids which contain an even number of carbon atoms melt at a higher temperature than the acid next in the series which contains an odd number of carbon atoms. This

peculiarity, the cause of which is not understood, has already been noted in the case of the saturated monobasic acids. It is also seen that the melting points of the acids with an even number of carbon atoms decrease with the increase in the number of carbon atoms in the molecule. The solubilities of the acids in water exhibit a similar irregularity. Those containing an uneven number of carbon atoms are much more soluble than those with an even number.

The acids in this series crystallize well, and those which contain more than three carbon atoms can be distilled under diminished pressure without decomposition. When heated at high temperatures under atmospheric pressure, water is given off and anhydrides are formed. The dibasic acids are not volatile with steam, and consequently can be readily separated from the lower fatty acids. The properties and reactions of a few typical members of the series will now be described in more detail.

136. Oxalic acid, $(COOH)_2$, is one of the longest-known organic substances. Its occurrence was first noted at the beginning of the seventeenth century, in the form of the acid potassium salt in sorrel. The acid crystallizes from water in the hydrated form, which contains two molecules of water of crystallization. It begins to lose water at 30°, and at 100° the loss is rapid. The acid sublimes with partial decomposition at 150° to 160°, and at a higher temperature is converted into water, carbon dioxide, carbon monoxide, and formic acid. The anhydrous acid is hygroscopic and is frequently used as a dehydrating agent. It is readily soluble in alcohol and sparingly soluble in ether. The acid and its salts are poisonous.

Oxalic acid occurs widely distributed in nature, usually in the form of the acid potassium or the calcium salt. Plants of the *oxalis* varieties contain appreciable quantities of the salts of oxalic acid. Rhubarb is especially rich in these salts. When the plant is covered with water it resists decay for a long time. The oxalic acid present is, in all probability, the agent which prevents the growth of the organisms which bring about putrefaction. Calcium oxalate frequently occurs in the urine as a crystalline sediment and in the cell walls of plants. The ammonium salt is found in guano. The acid is used in dyeing, in calico printing, and in analytical chemistry.

137. Preparation.—Oxalic acid resists the action of nitric acid and certain other oxidizing agents, and consequently is obtained when many complex organic compounds, such as sugars, cellulose, and starch, are subjected to oxidation. The acid can be obtained in a pure condition by gently heating cane sugar with about six times its weight of concentrated nitric acid. It is prepared commercially by heating wood shavings or sawdust with a strong aqueous solution of potassium and sodium hydroxides at 240° to 250°. The product of the reaction is taken up in water; milk of lime is added to precipitate calcium oxalate; and finally, the latter, after washing, is treated with sulphuric acid, which precipitates the calcium as sulphate and liberates the oxalic acid. A single recrystallization of the acid does not yield a chemically pure product, as the acid obtained in this way contains a small percentage of the difficultly soluble salts of the acid. The pure acid is best obtained by sublimation and subsequent crystallization of the slightly impure compound.

Synthesis.—Oxalic acid may be synthesized in the laboratory by methods which are of scientific interest. When an aqueous solution of cyanogen is allowed to stand, ammonium oxalate is formed:

$$\begin{matrix}CN\\|\\CN\end{matrix} + 4H_2O = \begin{matrix}COOH\\|\\COOH\end{matrix} + 2NH_3$$

$$(COOH)_2 + 2NH_3 = (COONH_4)_2$$

This reaction recalls the preparation of acetic acid from methyl cyanide:

$$CH_3CN + 2H_2O = CH_3COOH + NH_3$$

In both cases the CN radical is converted into the carboxyl group. When the alkali formates are heated away from air at about 400° a good yield of an oxalate is obtained:

$$2H.COONa = H_2 + (COONa)_2$$

Chemical Properties.—Oxalic acid undergoes a number of important decompositions. When heated with a dehydrating agent it is converted into carbon dioxide and carbon monoxide; sulphuric acid is usually used to effect the decomposition:

$$(COOH)_2 + H_2SO_4 = CO + CO_2 + H_2SO_4.H_2O$$

It has been mentioned above that heat alone brings about a partial decomposition of oxalic acid in this way. In the presence of uranium salts, which act as a catalytic agent, the decomposition of an aqueous solution of an oxalate into carbon monoxide and carbon dioxide takes place rapidly in the sunlight. It will be recalled that when heated with glycerol the products are carbon dioxide and formic acid, and that the acid is used in the preparation of allyl alcohol from glycerol (**105**).

Oxalic acid is readily oxidized by potassium permanganate, manganese dioxide, chromic acid, and other active oxidizing agents. It precipitates gold from its solution. The oxidation proceeds quantitatively according to the equation:

$$(COOH)_2 + O = 2CO_2 + H_2O$$

As the acid can be obtained in the pure condition it, or one of its salts, is used to standardize solutions of potassium permanganate to be used in volumetric analysis. The complete reaction is expressed by the equation:

$$5(COOH)_2 + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 10CO_2 + 8H_2O$$

Two molecules of potassium permanganate in the acid solution furnish five active oxygen atoms, which convert five molecules of oxalic acid into carbon dioxide and water. The rate of the oxidation of oxalic acid by potassium permanganate is markedly accelerated by the presence of manganous sulphate. At first, the reaction proceeds slowly but after a few drops of the solution of potassium permanganate have reacted, the decolorization takes place instantly.

Oxalic acid is one of the strongest of the organic acids, as it is highly ionized in aqueous solution. Its relation to other acids in this respect will be discussed at length later (**362**).

138. Oxalic acid shows many of the reactions which are characteristic of compounds containing the carboxyl group. It forms esters and other compounds. *Dimethyl oxalate*, $(COOCH_3)_2$, which melts at 54° and boils at 163.3°, can be made by heating together methyl alcohol and anhydrous oxalic acid.

The structure assigned to oxalic acid is deduced from the fact that it is a dibasic acid. The conclusion is in accord with

the formation of the acid as the result of the oxidation of glycol —a compound which is known to consist of two primary alcohol groups in combination with each other.

139. A number of the oxalates are of importance and of interest. All are insoluble in water except those which contain the alkali metals or ammonium. Neutral *potassium oxalate*, $K_2C_2O_4.H_2O$, dissolves in 3 parts of water at 16°. *Acid potassium oxalate*, KHC_2O_4, is much less soluble, 26 parts of water at 8° being necessary for its solution. The acid salt forms a compound with oxalic acid, which has the formula $KHC_2O_4.H_2C_2O_4.2H_2O$. It is called *potassium tetroxalate* or potassium quadroxalate, and as it can be readily obtained in a pure condition it is sometimes used in preparing standard solutions of alkalies and of potassium permanganate. The salt is sold under the name of "salt of sorrel," and is used to remove iron rust and ink stains from fabrics. The iron is converted by the salt into potassium ferrous oxalate, which is a yellow salt, soluble in water. In the case of an iron ink a similar reaction takes place. As many aniline dyes which are unaffected by oxalic acid are now used for inks, bleaching powder or other active oxidizing agents are often more efficient than oxalic acid in removing ink stains. *Calcium oxalate*, $CaC_2O_4.2H_2O$, is insoluble in water and acetic acid, but dissolves readily in mineral acids. It is precipitated when a soluble calcium salt is added to a neutral or an ammoniacal solution of an oxalate. The formation of the salt in this way, and its action with acetic acid and mineral acids, is often used as a *test for oxalic acid* and for calcium. A confirmatory test for oxalic acid is to heat the acid or its salt with concentrated sulphuric acid and ignite the carbon monoxide formed, which burns with a characteristic blue flame. As magnesium oxalate is insoluble in water and soluble in acetic acid, oxalic acid may be used to separate magnesium from calcium.

140. Malonic acid, $CH_2(COOH)_2$, is so called because it was first obtained as the result of the oxidation of malic acid. The acid is of particular interest, as many important compounds can be readily prepared as the result of reactions between its esters and other substances. The so-called malonic ester synthesis will be described later (**172**). Malonic acid crystallizes from water in laminae which melt at 135.6°, with partial decomposition. It can be prepared by a reaction which illustrates clearly the application of a general method emphasized in the case of acetic acid. The changes are indicated by the formulas

$$CH_3.COOH \longrightarrow CH_2Cl.COOH \longrightarrow CH_2CN.COOH \longrightarrow CH_2\begin{matrix}COOH\\COOH\end{matrix}$$

When malonic acid is heated at or above its melting poi decomposition takes place quantitatively according to th following equation:

$$CH_2\begin{matrix}COOH\\COOH\end{matrix} = CH_3COOH + CO_2$$

Other acids in which two carboxyl groups are joined to the sam carbon atom undergo a similar decomposition. It will be recalle that most compounds which contain two hydroxyl group linked to the same carbon atom are so unstable that they brea down spontaneously with the elimination of water. Maloni acid and its derivatives are more stable than the alcohols, a heating to the melting point is required to effect their decom position. The decomposition is of importance as it is frequentl made use of in the preparation of monobasic acids from dibasi acids of this type.

141. Succinic acid, $(CH_2.COOH)_2$, derives its name from th fact that it was first obtained as the result of the distillatio of amber (Latin, *succinum*). It occurs in fossilized wood, i many plants, and in the urine of horses, goats, and rabbits It can be made by the fermentation of the calcium salt of mali acid, which is a hydroxyl derivative of succinic acid (**320**).

The acid is formed in small quantities in the alcoholic fermenta tion of sugar, and in the oxidation of fats by nitric acid. Succini acid can be made by the application of the general syntheti methods of preparing acids. One method is indicated by th following formulas:

$$\begin{matrix}CH_2Br\\|\\CH_2Br\end{matrix} \longrightarrow \begin{matrix}CH_2CN\\|\\CH_2CN\end{matrix} \longrightarrow \begin{matrix}CH_2.COOH\\|\\CH_2.COOH\end{matrix}$$

Succinic acid is manufactured for commercial purposes by th electrolytic reduction of fumaric acid, $C_2H_2(COOH)_2$ (**143**) which is prepared from benzene, C_6H_6, a hydrocarbon present i coal tar. The acid is largely used in pharmaceutical preparations

Succinic acid melts at 185°. It boils with partial decomposi tion at 235°; water is eliminated and an anhydride is formed

$$\begin{matrix}CH_2COOH\\|\\CH_2COOH\end{matrix} = \begin{matrix}CH_2.C:O\\|\quad\diagdown O\\CH_2.C\ \ O\end{matrix} + H_2O$$

The same reaction is effected more completely by heating the acid with a dehydrating agent, such as phosphorus oxychloride. A small proportion of phosphorus pentachloride acts as a dehydrating agent and yields succinic anhydride. A larger proportion converts the acid into succinyl chloride.

142. Isosuccinic acid, $CH_3CH(COOH)_2$, is isomeric with succinic acid. As it is a methyl derivative of malonic acid and contains two carboxyl groups in combination with the same carbon atom, it resembles the latter in chemical properties. For example, when heated above its melting point it loses carbon dioxide and is converted into propionic acid:

$$CH_3CH(COOH)_2 = CH_3CH_2.COOH + CO_2$$

Dibasic acids in which the carboxyl groups are linked to different carbon atoms behave on decomposition by heat as succinic acid does, *i.e.*, they lose water, and anhydrides are formed. Isosuccinic acid is prepared from α-bromopropionic acid by the reactions with which the student is familiar. The acid forms crystals, which melt at 135°.

Unsaturated Dibasic Acids

143. Fumaric and Maleic Acids, $C_2H_2(COOH)_2$.—The unsaturated dibasic acids stand in the same relation to the unsaturated hydrocarbons as do the saturated acids to the paraffins. In both cases the acids may be considered as substitution products of the hydrocarbons in which hydrogen atoms are replaced by carboxyl groups. The relation is shown by the following formulas:

$$\begin{matrix} CH_3 \\ | \\ CH_3 \end{matrix} \qquad \begin{matrix} CH_2.COOH \\ | \\ CH_2.COOH \end{matrix}$$

Succinic acid

and

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} \qquad \begin{matrix} CH.COOH \\ \| \\ CH.COOH \end{matrix}$$

Maleic acid

The presence of a double bond in the unsaturated acids leads to an opportunity for isomerism like that shown by crotonic and isocrotonic acids (**130**). The two forms in the case of the dicarboxyl derivatives of ethylene are represented by the formulas:

(1) $\begin{matrix} HC.COOH \\ \| \\ HC.COOH \end{matrix}$ and (2) $\begin{matrix} HC.COOH \\ \| \\ HOOC.CH \end{matrix}$

144. Two acids are known to which these formulas are assigned The *cis* form (formula [1]) is given to maleic acid, and the *tran* form (formula [2]) to fumaric acid. The two acids differ mark edly in physical properties. Fumaric acid, which occurs some what widely distributed in plants, does not melt, but sublimes a about 200°. It is difficultly soluble in water. Maleic acid melt at 130.5°, is readily soluble in water and is a much stronger aci than fumaric acid (**362**). Both acids can be prepared by heatin malic acid, which is a hydroxyl derivative of succinic acid. I the temperature is kept between 130° and 150°, fumaric aci is obtained; when the acid is distilled, the chief product is th anhydride of maleic acid, which is readily converted into th acid by water. The reaction by which fumaric acid is obtaine is represented by the equation

$$\begin{matrix} CH.OH.COOH \\ | \\ CH_2COOH \end{matrix} = \begin{matrix} HC.COOH \\ \| \\ HOOC.CH \end{matrix} + H_2O.$$

This reaction is a further example of the preparation of a unsaturated compound by the removal of the elements of wate from a saturated compound. While succinic acid loses wate on heating and forms succinic anhydride, the decomposition o its hydroxyl derivative takes place in a manner which is analo gous to that in which the hydroxyl derivatives of the monobasi acids are decomposed by heat.

The preparation of fumaric acid by treating bromosuccini acid with potassium hydroxide is another illustration of a gen eral method which is much used to establish a double bond in compound:

$$C_2H_3Br.(COOH)_2 = C_2H_2(COOH)_2 + HBr$$

Maleic acid differs from fumaric acid in that it is converted int its anhydride when distilled:

$$\begin{matrix} HC.COOH \\ \| \\ HC.COOH \end{matrix} = \begin{matrix} HC.CO \\ \| \\ HC.CO \end{matrix} O + H_2O$$

It is for this reason that the *cis* formula is assigned to male acid. It seems probable that an anhydride could be forme more readily from a compound in which the carboxyl grou

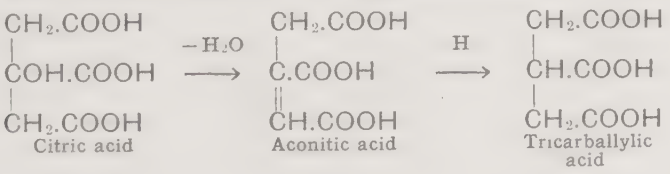
are present on the same side of the molecule, than from one in which these groups are on opposite sides. An examination of space models will make this clear. When fumaric acid is distilled, maleic anhydride is obtained. As the latter is readily converted into maleic acid by water, the reaction serves as a means of converting one isomer into the other. The conversion of maleic acid into fumaric acid may be effected by heating it for some time at a temperature slightly above its melting point, or by bringing it into contact with the halogen hydrides at ordinary temperature.

The heat of combustion of maleic acid is 326.1 Calories, and that of fumaric acid is 320 Calories. These values indicate that the change of maleic acid into fumaric acid takes place with the evolution of heat. When fumaric acid is exposed to ultraviolet light, energy is absorbed and it changes to maleic acid.

Both maleic and fumaric acids are reduced by nascent hydrogen to succinic acid—a reaction which is evidence of the correctness of the view that they are dicarboxyl derivatives of ethylene.

Maleic anhydride and fumaric acid are prepared on a large scale by passing the vapor of benzene, C_6H_6, mixed with air over vanadium oxide at about 450°. Maleic acid is used in the preparation of malic acid (**320**), and fumaric acid in the preparation of succinic acid.

145. Aconitic acid, $C_3H_3(COOH)_3$, is an example of an unsaturated tribasic acid. It occurs in the juice extracted from sugar cane. It is prepared by heating citric acid at 175°. Nascent hydrogen converts the acid into tricarballylic acid. These changes are clear from the following formulas:



Problems

1. (*a*) By what physical property other than melting point could malonic acid be readily distinguished from succinic acid? (*b*) By what chemical property could they be distinguished from each other?

2. How could you find out with the aid of a standardized solution of sodium hydroxide whether a compound having the molecular formula, $C_6H_{10}O_4$, contained one or two carboxyl groups?

3. Write equations for reactions by which (*a*) tricarballylic acid, $C_3H_5(COOH)_3$, may be prepared from glycerol, and (*b*) the acid of the structure $CH_3.CHCOOH.CH_2COOH$ may be prepared from *n*-propyl alcohol.

4. By what chemical tests could you distinguish the following: (*a*) $CH_3.CHCOOH.CH_2COOH$ and $CH_3.CH_2.CH(COOH)_2$; (*b*) $CH_3.CHOH.COOH$ and $CH_3.CH_2.COOH$; (*c*) $C_2H_2(COOH)_2$ and $C_2H_4(COOH)_2$?

5. Write the graphic formulas of and name the compounds formed by heating (*a*) $C_2H_5.CH(COOH)_2$ and (*b*) $(CH_3)_2C(COOH)_2$, by the action of (*c*) bromine on maleic acid, (*d*) hydrobromic acid on fumaric acid, (*e*) water on maleic acid, (*f*) hydrogen on aconitic acid.

6. Calculate the heat change involved in the following: (*a*) the reduction of maleic acid to succinic acid; (*b*) the conversion of maleic acid to malic acid; (*c*) the decomposition of malonic acid to acetic acid and carbon dioxide. The following heats of combustion are involved in the calculations: maleic acid, 326.1 Cal.; succinic acid, 356.8 Cal.; malic acid, 320.1 Cal.; acetic acid, 207.1 Cal.; H_2, 68.4 Cal.; malonic acid, 206.8 Cal.

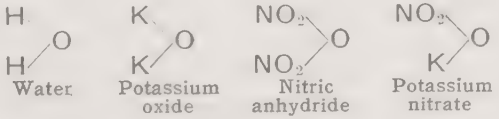
CHAPTER IX

ETHERS, ANHYDRIDES, AND ESTERS

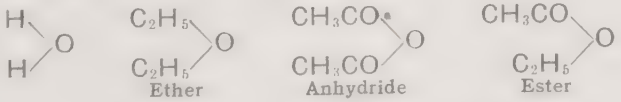
146. In the discussion of the chemical properties of alcohols and acids it was found convenient to consider these compounds as derived from water by the replacement of one hydrogen atom by alkyl and acyl radicals, respectively. The relation between the alcohols and inorganic bases, and between the organic and inorganic acids, is shown by the following formulas:

$H.OH$	$C_2H_5.OH$	$K.OH$	$CH_3CO.OH$	$NO_2.OH\ (HNO_3)$
	Alcohol	Base	Organic acid	Inorganic acid

The effect of the nature of the radical in combination with the hydroxyl group upon this group has been emphasized, and while marked similarities between the chemical behavior of alcohols and bases on one hand, and organic and inorganic acids on the other, have been noted, important differences have been pointed out. These relationships should be kept in mind in the consideration of the other substitution products of water which will now be discussed. Three important classes of compounds are formed as the result of the replacement of both hydrogen atoms in water. In the case of inorganic compounds the substances so formed are basic oxides, acid anhydrides, and salts; for example, the formulas of three well-known compounds written in this way are



With the organic compounds the three possible combinations are those which contain two alkyl radicals, two acyl radicals, and one alkyl and one acyl radical. The three classes are known as ethers, anhydrides, and esters respectively. The following formulas are illustrative:



It is thus seen that the ethers resemble in composition the metallic oxides, the anhydrides the inorganic anhydrides, and the esters the inorganic salts. The resemblance in composition indicated by the formulas finds expression in a similarity in chemical behavior of the analogous compounds. The differences between these organic and inorganic compounds are as marked, however, as in the case of alcohols and bases, and of organic acids and inorganic acids. The differences which are mainly of degree and not of kind are brought about as the result of the fact that the inorganic elements or groups are, in general, strongly positive or negative, whereas in the case of the organic compounds the positive or negative nature of the radicals is not so highly developed. The ethers are thus only weakly basic, and the esters resemble inorganic salts which are the product of the interaction of a weak acid and a weak base.

147. Ethyl ether, $(C_2H_5)_2O$, is the most important member of the class of compounds known as ethers. It is usually called *ether* (without the prefix ethyl).

Physical Properties and Uses.—Ether is a very mobile, colorless liquid, which boils at 34.5°, melts at −116.3°, and has the density 0.714 at $\frac{20°}{4°}$. On account of its low boiling point it is very volatile, and as its vapor forms an explosive mixture with air, great care must be exercised in its use. Ether is an excellent solvent for many organic substances, and is much used in the laboratory for crystallization and for extraction of substances from aqueous solutions. One volume of ether dissolves in about 11 volumes of water at 25°. As it is less soluble in water which is saturated with sodium chloride, the latter is frequently added to aqueous solutions which are to be extracted. Ether dissolves about 2 per cent of its volume of water. Continued inhalation of the vapor of ether causes unconsciousness. As its physiological effects can be more readily controlled than those of chloroform, it is widely used in surgery as an anesthetic.

Ether is formed when alcohol vapor is passed over aluminium oxide heated at 240° to 260°; it will be recalled that above 400° ethylene is produced.

Preparation.—Ether is usually prepared by the action of concentrated sulphuric acid on alcohol. For this reason it is sometimes called "sulphuric ether." Alcohol reacts with sulphuric

acid when gently heated and forms ethylsulphuric acid, which is the acid ethyl ester of sulphuric acid:

$$C_2H_5OH + H_2SO_4 = C_2H_5.H.SO_4 + H_2O$$

It will be recalled that the same reaction takes place in the preparation of ethylene (**37**), which is formed when the ester is heated to about 170°. If the temperature is maintained at 130° to 140° and alcohol is allowed to flow through the heated compound, a further reaction takes place according to the equation

$$C_2H_5.H.SO_4 + C_2H_5OH = (C_2H_5)_2O + H_2SO_4.$$

The sulphuric acid regenerated serves to convert more alcohol into ether. The process is thus a so-called continuous one. As only a part of the water formed distills over with the ether, the acid, which becomes more and more diluted as the reaction proceeds, finally ceases to react with the alcohol, and the production of ether stops. Other reactions take place which tend to interfere with the process; at the temperature used a part of the alcohol is oxidized and the sulphuric acid is reduced to sulphur dioxide. Notwithstanding these facts, sulphuric acid will convert about sixteen times its weight of alcohol into ether before the process becomes inefficient. If a small amount of aluminium sulphate (about 5 per cent) is added to the ethylsulphuric acid the conversion into ether takes place at about 120° without the formation of by-products.

Ether prepared by this process contains water, acid, and alcohol. It is purified by shaking it a number of times with small quantities of water, which free it from most of the alcohol. Acid is removed by shaking with a solution of sodium hydroxide. The ether is allowed to stand some hours in contact with anhydrous calcium chloride, from which it is distilled. This treatment removes most of the alcohol and water. Final purification is effected by adding metallic sodium in the form of a fine wire or thin shavings, and distilling when the evolution of hydrogen ceases and a fresh portion of sodium is without action. Ether should not be heated over a free flame, as its vapor is heavy and is apt to fall on the flame and ignite. It should be distilled from a bath which contains warm water.

148. Ether can be prepared from alcohol by a method which has great historical interest, as it was through the discovery of this method that the structure of ethers and their relation to

the alcohols were first made clear. When ethyl iodide is heated with sodium ethylate ether is formed:

$$C_2H_5ONa + C_2H_5I = C_2H_5OC_2H_5 + NaI$$

It has already been shown that in sodium ethylate, sodium is joined to oxygen. The simplest interpretation of the reaction just given—and the one which has proved correct—is that the ethyl group in the iodide takes the place of the sodium atom in the ethylate; sodium iodide and ether are formed. The formation of the so-called mixed ethers—compounds which contain two different alkyl groups linked to oxygen—is further evidence of the correctness of this interpretation of the reaction. When sodium methylate is heated with ethyl iodide, methyl ethyl ether is formed:

$$CH_3ONa + C_2H_5I = CH_3OC_2H_5 + NaI$$

If the view of the structure of ethers put forward is correct, we should expect to be able to prepare methyl ethyl ether as the result of the interaction of sodium ethylate and methyl iodide, thus:

$$C_2H_5ONa + CH_3I = C_2H_5OCH_3 + NaI$$

As methyl ethyl ether can be prepared in both these ways the view that it and other ethers are oxides of radicals in which the two alkyl groups are joined directly to oxygen appears to have a satisfactory experimental basis.

149. *Chemical Properties.*—The synthesis of *ether* indicates that it *is an oxide.* It does not, however, react readily with acids, nor does its aqueous solution affect indicators. In these respects it resembles the alcohols in which the properties of a base are but slightly developed. When ether is warmed with *concentrated hydriodic acid,* a reaction takes place which is analogous to that between a metallic oxide and an acid. Ethyl iodide is formed according to the following equation:

$$(C_2H_5)_2O + 2HI = 2C_2H_5I + H_2O$$

The reaction takes place quantitatively only in the presence of a large excess of the acid. With hydrochloric acid and hydrobromic acid analogous reactions do not take place so readily. The difference in chemical activity of the halogen acids, which has already been mentioned, is further emphasized by this case.

Ether dissolves in *cold concentrated sulphuric acid*. Addition of water to the mixture causes the precipitation of the ether unchanged. When gently heated with the acid, however, a reaction takes place in which the ether acts as an oxide, and an ester is formed:

$$(C_2H_5)_2O + 2H_2SO_4 = 2C_2H_5.H.SO_4 + H_2O$$

When heated with *water* in the presence of a small amount of acid, ether is converted into alcohol:

$$(C_2H_5)_2O + H_2O = 2C_2H_5OH$$

This reaction indicates that ether may be considered as the anhydride of alcohol.

Toward many of the common reagents ether is inert. It is unaffected by alkalies and metallic sodium, and dissolves in the cold the *halides of phosphorus* without undergoing change. By evaporation of the solution of phosphorus pentachloride in ether, a crystalline compound of the composition $[(C_2H_5)_2O]_2.(PCl_5)_3$ may be obtained. Ether forms similar so-called molecular compounds with a number of substances. Examples of these are substances to which have been assigned the formulas $(C_2H_5)_2O.Br_2$, $(C_2H_5)_2O.AlBr_3$, and $(C_2H_5)_2O.SnCl_4$.

When ether is heated with *phosphorus pentachloride*, the oxygen is replaced by its equivalent—two atoms—of chlorine:

$$\begin{matrix} C_2H_5 \\ C_2H_5 \end{matrix}\!\!>\!O + PCl_5 = \begin{matrix} C_2H_5Cl \\ C_2H_5Cl \end{matrix} + POCl_3$$

Chlorine and *bromine* react with ether and replace the hydrogen atoms by halogen. The reaction is analogous to that of these halogens with the hydrocarbons, acids, and other organic compounds. The extent of the substitution is affected by the temperature and the presence or absence of a catalytic agent and sunlight—conditions, it will be recalled, which are of the first importance in the replacement by halogen of hydrogen joined to carbon. The first product of the action of chlorine in the dark has the structure $CH_3CHCl.O.C_2H_5$. Substitution products are known up to the so-called perchloroether $(C_2Cl_5)_2O$.

150. Properties of the Ethers of Analytical Significance.—Many homologues of ether are known. With the exception of

those of very high molecular weight they are liquids, which have a specific gravity less than one, and are almost insoluble in water. Many ethers are decomposed when boiled with concentrated hydriodic acid, and alkyl halides are obtained. The inertness of ethers towards the reagents which are used to test for the presence of the characteristic groups in other compounds, serves as a guide in the determination of an unknown substance as an ether. Metallic sodium, which reacts with many organic compounds, does not affect ethers. Most of the ethers, like many other compounds which contain oxygen, are soluble without decomposition in cold concentrated sulphuric acid, from which they are precipitated unchanged on dilution with water. This behavior often serves to distinguish and separate ethers from other more or less inert substances such as the hydrocarbons, alkyl halides, etc.

Acid Anhydrides

151. Acetic anhydride, $(CH_3CO)_2O$, is the most important member of this class. It is a liquid which has an unpleasant, sharp odor, and boils at 139.6°. It is soluble in about 10 volumes of cold water, by which it is slowly converted into acetic acid. Its specific gravity is 1.082 at $\frac{20°}{4°}$.

Acetic anhydride is formed when acetic acid is passed over certain catalytic agents at a high temperature:

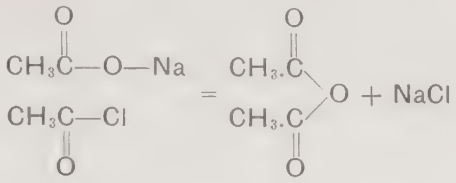
$$\begin{matrix} CH_3CO.OH \\ \\ CH_3CO.OH \end{matrix} \longrightarrow \begin{matrix} CH_3CO \\ \diagdown \\ O + H_2O \\ \diagup \\ CH_3CO \end{matrix}$$

If the vapors produced are rapidly cooled the anhydride can be obtained before it reacts with water and is converted back into the acid. This process has been patented recently and may become of industrial significance.

Acetic anhydride, as its name implies, is the anhydride of acetic acid. According to this view of its structure the compound consists of two acetyl groups $(CH_3C(=O)-)$ in combination with oxygen.

Preparation.—Evidence of the correctness of the above conception is furnished by the reaction by which the anhydride is

readily prepared. The method consists in heating a mixture of sodium acetate and acetyl chloride:



The reaction is analogous to that by which ether is prepared from sodium ethylate and ethyl iodide. It is an example of a general reaction which may be written thus:

$$R—O—Na + RCl = R—O—R + NaCl$$

where R represents an alkyl or acyl radical. In the case of acetic anhydride the radicals are both acetyl groups.

Manufacture.—Acetic anhydride is made on an industrial scale for use in the preparation of cellulose acetate and for other purposes. It is manufactured by heating sodium acetate with sulphur chloride, S_2Cl_2, at about 80°. It is probable that a part of the salt is first converted into acetyl chloride which then reacts as indicated above. The chloride is ordinarily prepared from glacial acetic acid and phosphorus trichloride. The replacement of these relatively expensive materials by those used in the commercial preparation, which can be obtained at a low price, made it possible to lower the cost of the anhydride and thus extend its use.

Chemical Properties.—The chemical behavior of acetic anhydride is in accord with the view of its structure which has been given. Like the anhydrides of inorganic acids it is converted by *water* into an acid:

$$(CH_3CO)_2O + H_2O = 2CH_3COOH$$

The reaction takes place rapidly in warm water.

Acetic anhydride reacts with *compounds which contain the hydroxyl group.* If this group is in combination with an alkyl radical the reaction takes place readily. For example, with alcohol, ethyl acetate is formed according to the following equation:

$$C_2H_5OH + (CH_3CO)_2O = CH_3CO.OC_2H_5 + CH_3COOH$$

As a result of the reaction the hydrogen in the hydroxyl grou in alcohol is replaced by the acetyl group. If a dihydroxy alcoh is used, two acetyl groups are introduced. The reaction is c great analytical value as by means of its use the number c hydroxyl groups present in a substance of unknown structur can be determined.

152. Acetic anhydride reacts slowly and only at somewhat elevated tem peratures with compounds which contain the hydroxyl group in combinatio with a negative or acid radical. Thus, when it is heated with butyric aci the hydrogen in the hydroxyl group is replaced by acetyl as in the case o alcohols:

$$\begin{matrix} CH_3CO \\ CH_3CO \end{matrix}\!\!>\!O + C_3H_7COOH = \begin{matrix} C_3H_7CO \\ CH_3CO \end{matrix}\!\!>\!O + CH_3COOH$$

The method serves, therefore, as a means of preparing mixed anhydrides

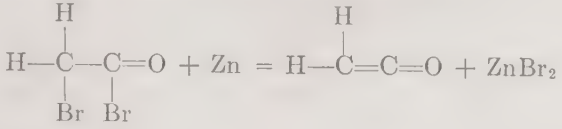
153. Acetic anhydride reacts with *ammonia* and forms a com pound, called acetamide, in which one hydrogen atom of the ammonia is replaced by the acetyl group:

$$(CH_3CO)_2O + 2NH_3 = CH_3CO.NH_2 + CH_3COONH_4$$

Compounds like acetamide, which are derivatives of acids in which the hydroxyl group is replaced by the NH_2 group, are of great importance, as they occur widely distributed in nature. They will be discussed in detail later. With *chlorine* and *bromine*, acetic anhydride forms substitution products.

154. Homologues of Acetic Anhydride.—A number of these are known. Those of high molecular weight are solids and have a specific gravity slightly less than one; they are conveniently prepared by heating the sodium salts of the acids with acetic anhydride. The anhydrides are insoluble in water, but dissolve in ether. Their boiling points are higher than those of the cor responding acids; thus, acetic acid boils at 118.1° and its anhy dride at 139.6°. They are all converted by water into acids, the reaction taking place more and more slowly with increasing molecular weight. The higher anhydrides can be treated with boiling water for some time with only partial conversion into the acid. Aqueous solutions of the alkalies, however, bring about the change rapidly.

155. Ketene, $CH_2{=}CO$.—If bromoacetyl bromide is heated with zinc the halogen atoms are removed and ketene is formed:



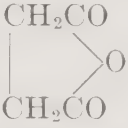
Ketene adds water energetically and is converted into acetic acid:

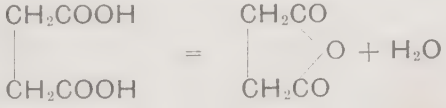
$$CH_2{=}CO + H_2O = CH_3COOH$$

It is, thus, an anhydride of acetic acid formed as the result of the removal of one molecule of water from *one* molecule of acetic acid. It is not classed, however, with the anhydrides of organic acids, which are formed as the result of the elimination of one molecule of water from two molecules of the acid.

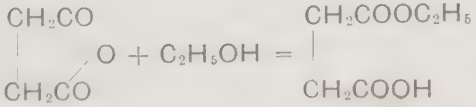
Ketene is a gas that liquefies at $-56°$. It reacts with the types of substances with which acetic anhydride reacts; the same compounds are formed with the two reagents. Acetic acid adds to ketene, and acetic anhydride is formed. Ketene polymerizes readily and consequently is unstable. It is most conveniently prepared by passing acetone through a tube heated to a high temperature:

$$CH_3COCH_3 = CH_2{=}CO + CH_4$$

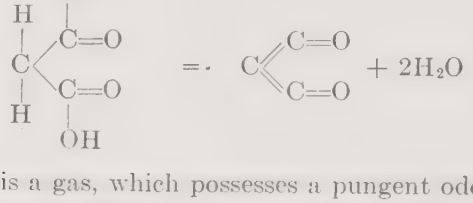
156. Succinic anhydride,  , is an example of an anhydride of a dibasic acid. Like the anhydrides of other dibasic acids in which the carboxyl groups are separated by two or three carbon atoms, it can be prepared by distilling the acid alone, or with better yield in the presence of a dehydrating agent. Acetic anhydride, acetyl chloride, or phosphorus oxychloride readily brings about the elimination of water:



Succinic anhydride is a colorless, crystalline substance, which melts at 119.6° and boils at 261°. It resembles the anhydrides of the fatty acids, being converted into the acid when boiled with water and into the acid ethyl ester when warmed with alcohol:



157. Carbon Suboxide.—An anhydride of malonic acid, $CH_2(COOH)_2$, which contains two carboxyl groups joined to the same carbon atom, has never been prepared. When the acid is slowly distilled with about ten times its weight of phosphorus pentoxide, a reagent which converts most acids into their anhydrides, it loses two molecules of water and is converted into a compound of the composition C_3O_2. On account of the fact that the product contains a smaller proportion of oxygen than that present in carbon monoxide it is called carbon suboxide. The method of preparation and properties of the oxide lead to the view that it has the structure represented by the formula given in the following equation:



Carbon suboxide is a gas, which possesses a pungent odor and can be condensed to a liquid which boils at 6.3°. It polymerizes on standing to a dark red amorphous substance. It is converted rapidly by water into malonic acid.

158. Properties of Acid Anhydrides of Analytical Significance.—In the identification of a substance as an acid anhydride, the conclusion is reached as the result of evidence that the compound contains only carbon, hydrogen, and oxygen, is neutral, is converted into an acid by water, and into an ester when treated with alcohol. As the chlorides, bromides, and iodides of the acids undergo similar changes the absence of halogen in the original compound must be proved. It has been pointed out that some anhydrides react slowly with water; in fact, some can be crystallized from this solvent unchanged. The apparent stability of a compound with water should not, therefore, lead to the definite conclusion that it is not an acid anhydride. Such anhydrides are readily converted into the sodium salts of the corresponding acids when warmed with a solution of sodium hydroxide. As esters yield sodium salts and alcohols when treated in this way, care should be taken to determine whether an alcohol is formed when the substance under study is decomposed by a solution of the base. The anhydride should be converted into an amide by treatment with ammonia in order to confirm the conclusions reached as the result of the application of the test just given. The determination of the

melting points or boiling points of the original substance and of the acid, ester, or amide prepared from it, serves to complete the identification of a substance the properties of which have already been described.

Esters

159. The esters are organic derivatives of acids in which the hydrogen atom of the acidic hydroxyl group is replaced by an alkyl radical. As many esters are volatile liquids they are sometimes called "ethereal salts." While, as will be shown later, the esters take part in certain reactions analogous to those characteristic of salts, they differ markedly from the latter in certain important respects. For example, while salts are highly ionized and enter instantaneously into reactions of double decomposition, the esters are not appreciably ionized, and the reactions in which they take part are often of a different character from those of salts. These differences are, no doubt, due to the fact that the alkyl radicals are only very weakly basic as compared with metals. The esters bear a striking resemblance to inorganic salts which are formed as the result of the interaction of a weak acid and a weak base. Like such salts they are hydrolyzed by water, but even in this case there is a difference, as the hydrolysis of salts takes place rapidly, whereas with esters reaction proceeds so slowly that its rate can be accurately measured. The reactions in the two cases are illustrated by the two equations

$$KCN + H_2O = KOH + HCN$$

$$CH_3COO.C_2H_5 + H_2O = C_2H_5OH + CH_3COOH.$$

Esters occur widely distributed in nature and give the characteristic odor to many flowers and fruits. They are manufactured in large quantities, and are used in perfumery and flavoring extracts.

Esters of Inorganic Acids

160. The esters of a number of inorganic acids are known. Those derived from the strong acids may be prepared directly from the acid and alcohol. In the case of the weak acids the esters can be prepared as the result of the interaction of the

silver salt of the acid with an alkyl halide; for example, ethy sulphite may be made by the reaction expressed by the equatio

$$2C_2H_5I + Ag_2SO_3 = (C_2H_5)_2SO_3 + 2AgI.$$

Only a few esters of inorganic acids will be described here. The esters of the halogen acids, which have been frequently mentioned, are discussed at length in Sec. **256.**

161. Ethyl nitrate, $C_2H_5NO_3$, is a liquid, heavier than water, which possesses a pleasant fruity odor, and boils at 88.7°. It is prepared by the action of nitric acid on alcohol:

$$C_2H_5OH + HNO_3 = C_2H_5NO_3 + H_2O$$

Heat is developed by the reaction, a part of the alcohol is oxidized, and a part of the acid reduced to nitrous acid, which forms ethyl nitrite with the alcohol present. The nitrate obtained in this way is, therefore, impure. In order to prevent the formation of ethyl nitrite, urea (**227**) is added to the mixture to interact with the nitrous acid formed:

$$CO(NH_2)_2 + 2HNO_2 = CO_2 + 2N_2 + 3H_2O$$

Unless carefully controlled the reaction between alcohol and concentrated nitric acid is apt to take place with explosive violence.

Ethyl nitrate is hydrolyzed by boiling water:

$$C_2H_5NO_3 + H_2O = C_2H_5OH + HNO_3$$

When reduced by the hydrogen generated by the action of tin on hydrochloric acid it is converted into alcohol and hydroxylamine:

$$C_2H_5O.NO_2 + 6H = C_2H_5OH + NH_2OH + H_2O$$

162. Ethyl nitrite, $C_2H_5NO_2$, is a liquid which boils at 17° and is soluble in water. It is prepared by distilling a mixture of alcohol, sodium nitrite, and concentrated sulphuric acid.

Ethyl nitrite shows the reactions characteristic of an ester. It is readily hydrolyzed by water. This action and the fact that on reduction it yields alcohol and hydroxylamine are evidence that its structure should be represented by the formula $C_2H_5—O—N=O$.

An alcoholic solution of ethyl nitrite is a pharmaceutical preparation sold under the name of "sweet spirit of niter."

163. Isoamyl nitrite, $C_5H_{11}NO_2$, which is used in the preparation of certain substances known as diazo compounds, is prepared from isoamyl alcohol by a method which is analogous to that used in the preparation of ethyl nitrite. It is a liquid of penetrating odor, which causes flushing of the face and vascular throbbing. Amyl nitrite is a valuable remedy used in medicine. Its physiological action is similar to that of glyceryl nitrate. It boils at 99°.

164. Methyl sulphate, $(CH_3)_2SO_4$, is an oily liquid which boils at 188.8° and is very poisonous. On account of its low cost it is frequently used instead of methyl iodide to introduce the methyl group into organic compounds. It is prepared by distilling under diminished pressure methyl hydrogen sulphate, which is formed by gently heating a mixture of methyl alcohol and sulphuric acid:

$$CH_3OH + H_2SO_4 = CH_3.HSO_4 + H_2O$$

$$2CH_3.H.SO_4 = (CH_3)_2.SO_4 + H_2SO_4$$

165. Ethyl hydrogen sulphate, $C_2H_5.HSO_4$, is an oily liquid, resembling sulphuric acid, which cannot be distilled without decomposition. It is usually called ethylsulphuric acid as it contains a hydrogen atom replaceable by metals. The acid is formed by heating at about 100° a mixture of alcohol with an excess of concentrated sulphuric acid over that required by the following equation:

$$C_2H_5OH + H_2SO_4 = C_2H_5.HSO_4 + H_2O$$

The acid may be separated from the excess of sulphuric acid by taking advantage of the fact that its barium salt is soluble in water, while barium sulphate is insoluble.

Ethylsulphuric acid is both an acid and an ester. When heated with water it is hydrolyzed:

$$C_2H_5.HSO_4 + H_2O = C_2H_5OH + H_2SO_4$$

The salts of ethylsulphuric acid and similar compounds are frequently used in the preparation of other substances. For

example, ethyl bromide and ethyl cyanide may be prepared by reactions which take place according to the following equations

$$C_2H_5.HSO_4 + KBr = C_2H_5Br + KHSO_4$$

$$C_2H_5.HSO_4 + KCN = C_2H_5CN + KHSO_4$$

Esters of Organic Acids

The general methods of preparation and the properties of the members of this class of compounds, of which many are known can best be made clear by a detailed consideration of a typical member of the group.

166. Ethyl acetate, $CH_3.COOC_2H_5$, the ethyl ester of acetic acid, is a colorless liquid of pleasant odor, which boils at 77.1° and has the specific gravity 0.899 at $\frac{20}{4°}$. It is soluble in 17 parts of water at 17.5°. It is formed as the result of the interaction of alcohol and acetic acid:

$$CH_3.COOH + C_2H_5OH = CH_3.COOC_2H_5 + H_2O$$

The reaction takes place very slowly at room temperature, and even when the mixture is heated many hours, complete reaction according to the equation does not take place. This is due to the slow rate of the reaction and to the fact that it is a reversible one. Reactions can take place according to the above equation when read either from left to right or from right to left. As the transformation of the acid into ester proceeds, a point is reached at which the ester formed from alcohol and acid is equal in amount to that hydrolyzed by the water which is formed in the reaction. When the so-called equilibrium is reached, further heating does not affect the course of the reaction. When equal molecular quantities of alcohol and acetic acid are heated, equilibrium is arrived at when about two-thirds of the acid has been converted into ester. The temperature at which the reaction is carried out has little effect on the equilibrium. Thus at 10° the limit of esterification is 65.2 per cent, while at 220° it is but 66.5 per cent when the liquids are heated together in a sealed tube. The rate at which equilibrium is reached, however, is markedly affected by temperature. In general, the rate of a reaction which is dependent upon temperature is doubled for each increase of 10°. It is clear from this why reacting substances are so frequently heated in the preparation of organic compounds

When equal molecular quantities of the vapors of ethyl alcohol and acetic acid are passed over finely divided silicon dioxide (silica gel) at 200°, 83 per cent of the reactants is converted into ethyl acetate. It appears from this that the equilibrium attained in the vapor phase is different from that attained in the liquid phase.

The rate at which an alcohol reacts with an acid and forms an ester, is markedly increased when the reaction takes place in the presence of a catalytic agent. Sulphuric acid and hydrogen chloride are frequently employed for this purpose; the former is usually used in the preparation of ethyl acetate.

Preparation.—Ethyl acetate is readily prepared by allowing a mixture of alcohol and acetic acid, in equivalent quantities, to flow into a mixture of alcohol and sulphuric acid heated to 140°. The sulphuric acid that takes part in the reaction is regenerated and the process is accordingly a continuous one, which, however, is subject to the limitations mentioned in the case of the similar process employed in the preparation of ether.

Manufacture.—Ethyl acetate is prepared industrially by distilling alcohol with dilute acetic acid containing a small amount of sulphuric acid. Although ethyl acetate is converted slowly by boiling water into alcohol and acetic acid, the process is a successful one because as the reaction proceeds a low-boiling mixture containing ethyl acetate is distilled off. Sulphuric acid is not used as a dehydrating agent in this case; it produces hydrogen ions which serve as a catalytic agent in bringing about the elimination of the elements of water from the reacting substances.

167. *Formation.*—Ethyl acetate may be formed by synthetic methods which are frequently used in the preparation of other members of this class. It is formed when alcohol is treated with acetic anhydride or acetyl chloride. The reactions which take place have already been mentioned. They are expressed by the following equations:

$$C_2H_5OH + (CH_3CO)_2O = CH_3COOC_2H_5 + CH_3COOH$$

$$C_2H_5OH + CH_3COCl = CH_3COOC_2H_5 + HCl$$

These reactions are of importance as they are examples of general reactions by which esters are formed as the result of the interactions of alcohols and anhydrides or acid chlorides.

A third method by which ethyl acetate may be formed is analogous to one of the methods used in the preparation of ethers and anhydrides. It consists in heating a salt of acetic acid with an ethyl halide:

$$CH_3COOK + C_2H_5I = CH_3COOC_2H_5 + KI$$

As in the two cases mentioned, the substance sought is formed as the result of the treatment of a compound containing a metal with a halogen derivative. The three cases differ only in the nature of the organic radicals in the compounds used. In the case of ethers both radicals are alkyl groups, while with esters one is an alkyl and the other an acyl group. The syntheses of these three classes of compounds bring out very clearly the relationship between them. The equations for the reactions are repeated here in order to emphasize this relationship:

$$C_2H_5.ONa + C_2H_5Br = C_2H_5.O.C_2H_5 + NaBr$$
$$CH_3CO.ONa + CH_3CO.Cl = CH_3CO.O.OC.CH_3 + NaCl$$
$$CH_3CO.ONa + C_2H_5Br = CH_3CO.O.C_2H_5 + NaBr$$

Chemical Properties.—The more important of these properties of ethyl acetate are (1) *hydrolysis:*

$$CH_3COOC_2H_5 + HOH = CH_3COOH + C_2H_5OH$$

The speed with which the reaction takes place is greatly increased in the presence of hydroxyl or hydrogen ions. When an alkali is used the acid formed is converted into a salt.

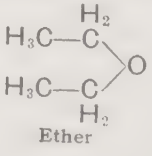
Ethyl acetate reacts with (2) a concentrated solution of *hydriodic acid:*

$$CH_3COOC_2H_5 + HI = CH_3COOH + C_2H_5I$$

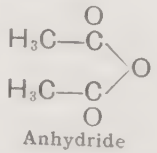
The ester is converted into acetamide by (3) *ammonia:*

$$CH_3COOC_2H_5 + NH_3 = CH_3CONH_2 + C_2H_5OH$$

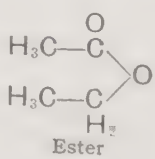
168. The Relationship between Esters, Ethers, and Anhydrides.—In chemical properties the esters resemble in some respects the ethers on one hand, and the anhydrides on the other. The relationship can be seen by comparing the graphic formulas of the three classes of compounds:



Ether



Anhydride



Ester

In the ethers the oxygen is linked to two carbon atoms joined to hydrogen. In the anhydrides the anhydride oxygen is linked to two carbon atoms joined to oxygen. In the esters the ester oxygen is linked to one of each kind of radical. The "breaking" of the two types of the carbon-oxygen bond is effected by different reagents at different rates. For example, water reacts with anhydrides at ordinary temperatures and with ethers only slowly at elevated temperatures. In the analogous reaction the behavior of esters lies between these two extremes; they react slowly with water at ordinary temperatures. It is evident that the bond that is broken is the one between the oxygen and the acyl radical; the latter adds hydroxyl, an acid is formed, and the C_2H_5O group takes up hydrogen and yields an alcohol.

The behavior of the three classes of compounds when heated with a solution of hydriodic acid can be interpreted in a similar way. Ethers are converted into iodides in this way. Anhydrides do not yield iodides under these conditions but are converted into acids by the water present. Esters behave as might be expected; the alkyl radical is converted into an iodide and the acyl radical into the acid:

$$CH_3COOC_2H_5 + HI = CH_3COOH + C_2H_5I$$

Ethers, esters, and anhydrides dissolve in cold concentrated sulphuric acid. When the solutions are poured on ice the ethers and esters are recovered unchanged; the anhydrides are rapidly hydrolyzed. If the mixtures are heated and then poured into water, ethers and esters yield alkylsulphuric acids:

$$C_2H_5OC_2H_5 + 2H_2SO_4 = 2C_2H_5SO_4H + H_2O$$
$$CH_3COOC_2H_5 + H_2SO_4 = C_2H_5SO_4H + CH_3COOH$$

Ammonia does not react with ethers under ordinary conditions but changes anhydrides into amides (**153**). In the reaction the carbon-oxygen bond is broken; NH_2 adds to the acyl radical to form the amide and hydrogen to the rest of the molecule to form the acid:

$$\begin{matrix} CH_3CO \\ CH_3CO \end{matrix}\!\!>\!O + NH_3 = CH_3CO.NH_2 + CH_3COOH$$

A similar reaction takes place in the case of esters; the bond linking the oxygen atom to the acyl radical is broken: but in this

case an amide and an alcohol are formed, since ammonia does not affect the alkyl-oxygen bond:

$$\begin{matrix} CH_3CO \\ C_2H_5 \end{matrix}\!\!>\!O + NH_3 = CH_3CO.NH_2 + C_2H_5OH$$

Homologues of Ethyl Acetate

169. The esters of the fatty acids resemble ethyl acetate in physical properties and in their behavior with other substances. It has been stated that they possess characteristic odors, and that some are manufactured and used in artificial flavoring extracts. As examples may be given *isoamyl acetate*, $CH_3COOC_5H_{11}$, which on account of its odor is sometimes called "banana oil," *methyl butyrate*, $C_3H_7COOCH_3$, which has the odor of pineapples, *isoamyl isovalerate*, $C_4H_9COOC_5H_{11}$, which has that of apples, and octyl acetate, $CH_3COOC_8H_{17}$, the odor of which resembles that of oranges.

Most of the esters of the monocarboxylic acids are liquids which have specific gravities less than one, and are insoluble in water. Some of high molecular weight are solids; for example, *cetyl palmitate*, $C_{15}H_{31}COOC_{16}H_{33}$, forms crystals which melt at 49°.

Esters can be prepared in many cases by the action of alcohols on acids in the presence of sulphuric acid. Certain alcohols are very readily converted into unsaturated hydrocarbons by concentrated sulphuric acid. For this and other reasons hydrogen chloride is frequently used instead of sulphuric acid. The usual practice is to saturate with hydrogen chloride only about 4 to 5 per cent of the alcohol to be used, and to boil a mixture of the solution so prepared with the rest of the alcohol and the organic acid for two or three hours. The ester is obtained, as before, by precipitation with water.

Esters can be prepared by heating a mixture of a salt of the acid and an alcohol with concentrated sulphuric acid. The latter liberates the organic acid and the excess used serves to catalyze the reaction.

170. Effect of the Structure of Alcohols and Acids on Rates of Esterification.—The extent to which a reaction takes place between an alcohol and an

acid is markedly affected by the nature of the radicals present in each. A quantitative study of the rates of the reactions when alcohols and acids of different structures are heated together has brought out some interesting facts in regard to the effect of structure on chemical reactivity. When primary alcohols are heated in sealed tubes for an hour at 154° with an equivalent quantity of acetic acid, about 47 per cent of the alcohol is converted into ester. Secondary alcohols under the same conditions yield about 22 per cent of ester, and tertiary alcohols only about 1.5 per cent. These results illustrate clearly the great effect on the reactivity of a compound of the nature of the radical which it contains. They also serve to emphasize the difference between primary, secondary, and tertiary alcohols, which has already been discussed. It will be remembered that the general formulas of these three classes of alcohols are $RCH_2.OH$, RR'CH.OH, and RR'R''C.OH, respectively.

The determination of the rate of esterification of one alcohol with acids of varying structures brought out similar results in regard to the effect of the nature of the radicals on the reactivity of acids. Acids which contained a primary radical, $RCH_2.COOH$, were converted into esters most rapidly, and those containing a secondary alkyl, RR'CH.COOH, less rapidly. Esters were formed very slowly from acids which contained a tertiary group, RR'R''C.COOH. The exact significance of these and other results of a similar nature has not as yet been made clear. It is probable that a quantitative study of the effect of structure on chemical reactivity will eventually throw much light on the nature of molecules and on the manner in which they react with one another.

The quantitative study of the rate of hydrolysis of esters has led to results of the greatest value to the science of chemistry in general. The fact has been mentioned that the rate of hydrolysis is markedly affected by the presence of acids or bases, which are said to act as catalytic agents. The experimental results obtained show that the rate is determined by the concentration of the hydrogen or hydroxyl ions, and is independent of the acid used. After the rate of hydrolysis of an ester with an acid of known ionization has been determined, a study of the rate of hydrolysis of the same ester with other substances which produce hydrogen ions serves to determine the extent of ionization of these substances. The nature of catalytic action has become more thoroughly understood as the result of the quantitative study of reactions of hydrolysis.

Although much attention has been devoted to the study of esters, the mechanism of the reaction which takes place in their formation from acids and alcohols is not yet understood. There is evidence that the reaction is not one of neutralization like that of an acid and a base, and that it may involve the elimination of the hydroxyl group from the acid and the hydrogen from the alcohol (**417**). There is ample opportunity to study the way in which organic molecules interact—a subject of the greatest importance which has received some attention lately.

Esters of Dibasic Acids

171. Ethyl malonate, $CH_2(COOC_2H_5)_2$, which is often called malonic ester, is the most important member of this class on account of its frequent use in syntheses. It can be prepared from alcohol and malonic acid but is usually made from chloroacetic acid by the reactions indicated by the following equations:

$$CH_2\begin{matrix}Cl\\COOK\end{matrix} + KCN = CH_2\begin{matrix}CN\\COOK\end{matrix} + KCl$$

$$CH_2\begin{matrix}CN\\COOK\end{matrix} + KOH + H_2O = CH_2\begin{matrix}COOK\\COOK\end{matrix} + NH_3$$

$$CH_2\begin{matrix}COOK\\COOK\end{matrix} + 2C_2H_5OH + H_2SO_4 =$$

$$CH_2\begin{matrix}COOC_2H_5\\COOC_2H_5\end{matrix} + K_2SO_4 + 2H_2O$$

Ethyl malonate is a liquid of faint odor, which boils at 198.9° and has the density 1.054 at $\frac{20°}{4°}$.

172. Malonic Ester Synthesis.—When ethyl malonate is treated with sodium, hydrogen is evolved and a compound is formed from the ester as the result of the replacement of hydrogen by the metal. If the weights of the substances taken are in the relation of one molecular weight of the ester to one atomic weight of sodium, the resulting compound has the composition represented by the formula $CHNa(COOC_2H_5)_2$. If twice as much sodium is used, two atoms of the metal are introduced and the formula of the sodium derivative is $CNa_2(COOC_2H_5)_2$. The structure of these sodium derivatives has not been definitely established, but many of their reactions can be interpreted most readily with the aid of the formulas given, and, accordingly, they will be used in the considerations which follow. It is probable that they resemble in structure the analogous compounds derived from acetoacetic ester (**343**). Monosodium and disodium malonic ester, like other organic compounds which contain metals react with many organic substances which contain halogen atoms. Two typical reactions are represented by the following equations:

$$NaCH(COOC_2H_5)_2 + C_2H_5I = C_2H_5CH(COOC_2H_5)_2 + NaI$$

$$Na_2C(COOC_2H_5)_2 + 2C_2H_5I = (C_2H_5)_2C(COOC_2H_5)_2 + 2NaI$$

By saponification of the products of the reaction, dicarboxylic acids are obtained. As the ethyl iodide given in the reactions above can be replaced by many other halogen compounds, it is evident that this synthetic method can be used in the preparation of a large number of compounds of this type.

It will be recalled that dicarboxylic acids which contain two carboxyl groups in combination with the same carbon atom, readily pass into monocarboxylic acids, with loss of carbon dioxide, when heated. This fact renders the malonic ester synthesis of great value in the preparation of monocarboxylic acids. When the acids which have been just used as illustrations are heated, they decompose according to the following equations:

$$C_2H_5CH(COOH)_2 = C_2H_5CH_2\,COOH + CO_2$$

$$(C_2H_5)_2C.(COOH)_2 = (C_2H_5)_2CH.COOH + CO_2$$

If it is desired to introduce two different radicals the synthesis is carried out in steps: From ethyl malonate can be obtained the ester formed by the replacement of one hydrogen by an alkyl group, for example, $CH_3CH(COOC_2H_5)_2$. This, like the ester of malonic acid, reacts with sodium and forms a derivative which may be condensed with a molecule of another alkyl halide, thus:

$$CH_3CNa(COOC_2H_5)_2 + C_2H_5I = \begin{matrix} CH_3 \\ C_2H_5 \end{matrix}\!\!>\!C(COOC_2H_5)_2 + NaI$$

A monocarboxylic acid is formed, as before, by heating the acid obtained from the ester:

$$\begin{matrix} CH_3 \\ C_2H_5 \end{matrix}\!\!>\!C(COOH)_2 = \begin{matrix} CH_3 \\ C_2H_5 \end{matrix}\!\!>\!CHCOOH + CO_2$$

As other classes of compounds are prepared from acids, and as the malonic ester synthesis furnishes evidence of the structure of acids prepared through its aid, the synthesis has been of great service in the building up of compounds and in the determination of structure.

In carrying out the preparation of acids in this way the sodium derivatives of malonic ester are first prepared by adding the ester to the calculated weight of sodium ethylate dissolved in alcohol. A reaction takes place according to the equation

$$CH_2(COOC_2H_5)_2 + C_2H_5ONa = CHNa(COOC_2H_5)_2 + C_2H_5OH.$$

The halide is now added and the mixture boiled until the solution becomes neutral. Addition of the mixture to water causes the solution of the sodium halide formed and the precipitation of the ester produced by the reaction.

Esters of Polyhydroxy Alcohols. Fats

173. The most important members of this class of compounds are the so-called *glycerides*, which are esters of glycerol; for example $(C_{15}H_{31}COO)_3C_3H_5$. The *fats* and *vegetable oils* are mixtures of esters, which on hydrolysis yield glycerol and homologues of acetic acid together with oleic acid and small amounts of other unsaturated acids. The glycerides composing the greater part of the fats and oils of commercial importance, are those of butyric, lauric, palmitic, stearic, oleic, linoleic, and ricinoleic acids. In addition, some fats contain, in relatively small proportions, the glycerol esters of caproic, caprylic, crotonic, and myristic acids.

The fats and oils obtained from various sources differ from one another in the proportion of the several esters present in each. This difference in composition results in a difference in physical properties, such as specific gravity, viscosity, index of refraction, and melting point. All the fats and vegetable oils are soluble in ether, however—a fact made use of in the analysis of foods to separate fats from the other constituents of food products. As the physical properties of a fat or an oil obtained from a definite source are more or less constant, the determination of these properties is of value in the analysis of such substances. The chemical analysis of fats and oils is based upon determinations of the proportion of unsaturated compounds present, of the relation between the acids of low and high molecular weight obtained on hydrolysis, and of the proportion of substances which do not undergo hydrolysis. This statement will be made clearer by a brief consideration of a few of the more important methods employed in the analysis of fats and oils.

Iodine Value.—It will be recalled that unsaturated compounds unite directly with halogens and form addition products. As the glycerides of the unsaturated acids enter into combination with iodine, the amount of the halogen which reacts when a definite weight of fat or oil, dissolved in chloro-

form, is treated with an alcoholic solution of iodine, is a measure of the extent to which unsaturated compounds are present. Reaction between the oil and the halogen takes place more readily in the presence of mercuric chloride. The number obtained by dividing the weight of iodine which reacts by the weight of the oil used, and multiplying by 100, is called the *iodine value*. It is evident that if an oil contains much olein its iodine value will be high, while one containing a small proportion of unsaturated compounds will give a correspondingly small iodine value. Thus, cottonseed oil has 111 to 116 as its iodine value, while that of coconut oil is 8.5 to 9. The *elaidin test*, which has already been mentioned (**131**), is also a measure of the unsaturation of the fat or oil.

The Reichert-Meissl number of an oil is determined by the percentage of acids, soluble in water and volatile with steam, which is obtained when the fat is hydrolyzed. The method of analysis consists in saponifying a definite weight of fat with an alcoholic solution of sodium hydroxide, distilling off a definite volume of the solution after adding dilute sulphuric acid, and finally determining by titration the amount of acid in the filtered distillate. The number of cubic centimeters of tenth-normal alkali required to neutralize the soluble acids volatile with steam, which are obtained from 5 grams of the fat or oil, is called its *Reichert-Meissl number*. Of the fatty acids only those of low molecular weight are soluble in water and volatile with steam. The common fats differ in the proportion in which the glycerides of these acids are present. Thus the Reichert-Meissl number of butter fat is 22 to 30, while that of lard is less than 0.5.

The Hehner value expresses the relation between the insoluble and soluble acids obtained from the fat by hydrolysis.

The estimation of the *unsaponifiable matter* in certain oils is frequently of value. Most fats and oils contain substances which are not changed when heated with a solution of an alkali. As glycerides are converted by this treatment into glycerol and sodium salts of acids, substances soluble in water, the percentage of the material present which does not undergo hydrolysis can be determined. The presence of paraffin, mineral oils, and other hydrocarbons can be determined by this test. Certain solid alcohols are present in some animal fats and edible oils. As they are not affected by a solution of sodium hydroxide they are obtained along with other unsaponifiable matter. The alcohols which occur most frequently are cholesterol, $C_{27}H_{45}OH$, the esters of which are present in wool grease and are used in pharmacy under the name lanolin in the preparation of ointments; phytosterol, a constituent of certain vegetable oils; and sitosterol, which is present in some cereals. Phytosterol and sitosterol appear to be isomers of cholesterol; the structures of the three alcohols are not known.

174. A few fats and oils will be described briefly as examples:

Cottonseed oil is obtained from the seeds of the cotton plant. It contains stearin, palmitin, olein, and linolein. It is used for cooking purposes, as a salad oil, in the manufacture of soap, as an adulterant for olive oil, butter, and lard and in the manufacture of butter substitutes. The iodine value of the refined oil is 111 to 116.

Olive oil, which is obtained from the fruit of the olive tree, contains abou 28 per cent of solid fat consisting of palmitin and a little arachidin. The res is mostly olein. Substances present in smaller quantities are linolein, choles terol, free fatty acids, and unsaponifiable matter. The oil is used as a sala oil, as a lubricant, in soap stock, and for other purposes. Its iodine value i 77 to 88. The elaidin test produces a solid mass within 2 hours. O account of its high cost it is frequently adulterated with cottonseed, peanut lard, and other oils.

Cod-liver oil, obtained from the liver of the codfish, is an example of fish oil. It contains the glycerides of oleic, myristic, palmitic, and steari acids, some volatile fatty acids, and some cholesterol. Traces of iodine an phosphorus are also present. The oil is used in medicine. The oil is readil digested and assimilated and the presence in it of vitamines has led to it extensive use as a cure for rickets and as a constituent in the food o growing children.

Lard is prepared from the fat of the hog. It consists of stearin, palmitin and olein, with a small amount of linolein. Fresh lard contains but a smal amount of free acid (0.1 to 0.4 per cent). On exposure to the air partia decomposition takes place and the acidity increases. The iodine value of old lard is less than that of the fresh substance.

Tallow is the solid fat of the sheep or ox. It consists of almost two-thirds palmitin and stearin, and one-third olein. It is extensively used for soap and candle stock, for lubricating, and as a dressing for leather.

Butter is a mixture of fat, water, curd, milk sugar, and salts. The amount of fat varies between 78 and 94 per cent. Butterfat differs from other animal fats in that it contains an appreciable proportion of glycerides of the fatty acids of low molecular weight. It contains about 60 per cent olein, 30 per cent palmitin and stearin, and 5 per cent butyrin. Small amounts of the glycerides of capric, caprylic, myristic, and other acids are present. Butterfat, on account of the comparatively high percentage of volatile acids which it contains, gives a large Reichert-Meissl number, 22 to 30. Butter is usually colored by the addition of carrot juice, turmeric, or annatto; synthetic coal-tar dyes are also used at times. The rancidity of butter is produced as the result of bacterial action, by which butyric and other acids having a disagreeable odor and taste are produced.

Oleomargarine and other butter substitutes are made from mixtures of animal and vegetable oils. The olein from tallow, lard, or cottonseed oil is frequently used. These are colored and mixed with a small proportion of butter, or churned with milk in order to give the product the appearance and taste of butter. Oleomargarine can be distinguished from butter by the determination of the Reichert-Meissl number of each. That of the former is seldom more than 1, while that of butter is from 22 to 30.

175. The melting points of fats vary markedly with the proportion of the unsaturated esters present, for these are liquids at ordinary temperatures. The more highly unsaturated esters undergo oxidation more or less rapidly and yield compounds possessing a disagreeable odor. For these reasons certain fats are not adapted to important uses, such as cooking, soap

making, etc. The discovery that hydrogen can be added to the unsaturated compounds at a relatively low temperature if the reaction is brought about in the presence of finely divided nickel, has revolutionized the industries based on the use of fats. Large quantities of vegetable oils are now converted into solid fats in this way and are used as a substitute for lard in cooking. Oils that could not be used in the past are now converted into soap after hydrogenation. The extent to which the oil is hardened depends upon the amount of hydrogen added. The highly hydrogenated oils, which are solids, have found an application in cooking because they possess a "shortening" effect superior to that of lard.

176. Fats as Foods.—Fats are valuable food products; since they possess a relatively small percentage of oxygen they produce a large amount of heat when they are oxidized in the animal body to carbon dioxide and water. Since one of the important functions of foods is to keep the body at a temperature which is ordinarily above that of the air, fats serve admirably this purpose. The percentages of the elements in fats are approximately as follows: carbon 76, hydrogen 12, and oxygen 12. The carbohydrates, of which starch and sugar are examples, contain a higher percentage of oxygen; for example, starch, which is the principal constituent of bread and such vegetables as potatoes, contains 44.4 per cent of carbon, 6.2 per cent of hydrogen, and 49.4 per cent of oxygen. The proteins which are the nitrogenous constituents of foods contain from 51 to 55 per cent carbon, 6 to 7 per cent hydrogen, 20 to 25 per cent oxygen, 15 to 17 per cent nitrogen, and from 0.3 to 2.5 per cent sulphur. It is evident from these figures why fats in which the carbon and hydrogen are oxidized to but a slight extent yield a relatively high amount of heat on complete oxidation.

One gram of fat yields on combustion in the body 9,450 calories; 1 gram of starch and other carbohydrates 4,100 calories, and 1 gram of protein 4,350 calories. The natural dietaries of men are in accord with these facts. People who live in very cold regions eat large quantities of fat, whereas in the tropics the starch obtained from plants and fruits is the chief constituent of the diet.

The digestion of fat in the animal body consists in the hydrolysis of the fat to free acids and glycerol. This change is brought about through the catalytic influence of complex organic substances known as enzymes (**372**) which are found in the gastric juice of the stomach and the pancreatic juice of the small intestine. These enzymes are known as lipases. The digestion of fat begins in the stomach but takes place to a slight degree only since lipases function best in alkaline solution and when the fat is in an emulsified condition. The fat in milk is present as an emulsion and is in a condition to be hydrolyzed. Digestion takes place largely in the small intestine under the influence of the pancreatic lipase, called *steapsin*, and of the bile, which is a secretion of the liver that flows into the small intestine. The bile is alkaline and emulsification of the fat takes place. The acids formed react with the alkali present and soaps are produced which markedly assist in the emulsification. The salts and glycerol thus formed are absorbed through the walls of the intestine and pass to the lymphatic circulatory system and the blood.

It is probable that the emulsified fat is also absorbed directly. T products of the hydrolysis are synthezised into fats and are carried by t blood in the form of an emulsion to the muscle cells where they are oxidize If more fat is eaten than is required by the body it is resynthesized aft digestion and deposited as adipose tissue, which serves as a storehouse available energy.

Waxes

177. The waxes consist essentially of esters of the highe saturated monohydroxy alcohols and the higher fatty acid *Sperm oil* is a liquid wax obtained from the blubber and hea cavity of the sperm whale. It contains no glycerides, but prob ably consists of the esters of dodecyl alcohol, $C_{12}H_{25}.OH$; cety alcohol, $C_{16}H_{33}.OH$; and other saturated alcohols. It is use as an illuminant, for leather dressing, and in the temperin of steel.

Spermaceti, which is a crystalline wax obtained from sperm oil, consists mainly of cetyl palmitate, $C_{15}H_{31}COOC_{16}H_{33}$. I is used in candle making, in confectionery, and in perfumery.

Beeswax is obtained from the honeycomb of bees; it consist chiefly of the palmitic ester of myricyl alcohol, $C_{15}H_{31}COOC_{31}H_{63}$ Some cerotic acid, $C_{25}H_{51}COOH$ and certain hydrocarbons ar also present in the wax. It finds many uses in the arts.

Carnauba wax is an example of a vegetable wax. It form as a coating on the leaves of a species of palm. It contains among other substances, myricyl alcohol, $C_{31}H_{63}OH$, cerotic acid, $C_{25}H_{51}COOH$, and myricyl cerotate. It is used for candle making, in varnishes, and for adulterating beeswax.

178. Properties of Esters of Analytical Significance.—The property of esters which is most frequently made use of in their identification is their ability to undergo hydrolysis. All esters are converted into alcohols and sodium salts of acids when heated with an aqueous solution of sodium hydroxide. When the hydrolysis has been effected, the mixture is distilled if the alcohol formed is soluble and volatile with steam. The alcohol is obtained by saturating the distillate with potassium carbonate. The layer which separates is dried over lime and distilled. If an insoluble alcohol is formed, it is separated, dried, and distilled. The acid formed from the ester can be isolated by precipitation from its sodium salt with hydrochloric acid.

if it is insoluble in water. If soluble, the solution of its salt is evaporated to dryness, and the residue distilled with concentrated sulphuric acid. The physical properties of the ester, together with those of the alcohol or acid derived from it, serve to identify it. Hydrolysis of esters is often carried out in alcoholic solution in the case of those which are soluble in alcohol, as reaction takes place more quickly when the reacting substances are in solution.

Many esters are soluble in cold concentrated sulphuric acid. This property serves to distinguish them from hydrocarbons, alkyl halides, and many other compounds.

Some esters react with sodium with the evolution of hydrogen when they are treated with the metal. Ethyl acetate undergoes a profound change when heated with sodium. The fact is mentioned here as it has been pointed out that sodium is frequently used in testing for the presence of a hydroxyl group in organic compounds. As simple esters do not contain this group, it is seen that the formation of hydrogen when a compound is treated with sodium is not positive evidence that a hydroxyl group is present. Notwithstanding this limitation, the test is a valuable one, and is frequently used in the investigation of substances of unknown structure. Most esters are liquids or solids, which are insoluble in water, and have specific gravities less than one.

Problems

1. (*a*) Summarize in the form of equations the general methods that can be used to prepare either esters, ethers, or anhydrides. (*b*) State in the case of each class of compounds the most convenient method. (*c*) Write also equations for special methods that can be used in the preparation of members of each class.

2. Compare the action of the following reagents on ethers, esters, and anhydrides: (*a*) water, (*b*) sodium hydroxide, (*c*) chlorine, and (*d*) ammonia.

3. How could you distinguish by chemical tests the following: (*a*) $(C_3H_7)_2O$, $C_3H_7COOC_3H_7$ and $(C_3H_7CO)_2O$; (*b*) C_3H_7OH, $(C_3H_7)_2O$ and C_3H_7COOH; (*c*) $CH_3.CHOC_2H_5.COOH$, $CH_3.CHOC_2H_5.COOC_2H_5$ and $CH_3.CHOH.COOC_2H_5$?

4. How could you separate without the use of distillation (*a*) petroleum ether from ethyl acetate; (*b*) ethyl ether from ethyl bromide; (*c*) petroleum ether from ethyl ether?

5. Write equations for reactions that take place when the following are heated with an excess of a concentrated solution of hydriodic acid: (*a*)

$(C_2H_5)_2O$, (*b*) $(C_2H_5CO)_2O$, (*c*) $C_2H_5COOC_2H_5$, (*d*) $CH_3.CHOH.COOC_2H$

6. Write equations for the reactions that take place when the compoun listed in question 5, above, are heated with a solution of sodium hydroxid

7. Show how acids of the following structures may be prepared by mea of the malonic ester synthesis: (*a*) $CH_3.CH_2.CH_2COOH$, (*b*) *n*-C_4H $CH(COOH)_2$, (*c*) *iso*-$C_3H_7.COOH$, (*d*) $CH_3OCH_2CH_2CH_2COOH$.

8. How could isobutane be prepared from isopropyl iodide and malon ester?

9. How could you distinguish beeswax from a solid fat?

10. With the aid of a standardized solution of sodium hydroxide ho could you distinguish cetyl palmitate from glyceryl palmitate?

11. How could you distinguish (*a*) a mineral oil from a vegetable oil, (a nondrying oil from a drying oil, (*c*) a fat from a wax, and (*d*) butter fro oleomargarine.

12. Two compounds each having the formula $C_7H_{14}O_2$ reacted with boiling solution of sodium hydroxide. One yielded a compound having th formula $C_3H_5O_2Na$ and the other the compound $C_5H_9O_2Na$. Write th graphic formulas of the four compounds.

13. A compound of the formula $C_4H_8O_3$ was converted into the sa $C_3H_5O_3Na$ when boiled with a solution of sodium hydroxide. Write tw possible graphic formulas for the original compound.

CHAPTER X

ALDEHYDES AND KETONES

179. In the discussion of alcohols it was noted that they are converted by active oxidation into acids. By careful regulation of the process, however, intermediate compounds are obtained in the case of primary and secondary alcohols. The reactions in the case of primary alcohols may be illustrated by the equations which express the oxidation of ethyl alcohol:

$$C_2H_6O + O = C_2H_4O + H_2O$$
$$C_2H_4O + O = C_2H_4O_2$$

The first change consists in the removal of two hydrogen atoms and the formation of a substance which is known as an aldehyde (from *al*cohol *dehyd*rogenatus). Addition of oxygen converts the aldehyde into an acid with the same number of carbon atoms.

In the case of a secondary alcohol, the first step brings about a change similar to that which takes place when a primary alcohol is oxidized. The oxidation of isopropyl alcohol—the secondary alcohol which contains the smallest number of carbon atoms—is represented by the following equation:

$$C_3H_8O + O = C_3H_6O + H_2O$$

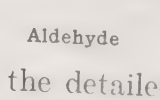
The substance formed in this case is called acetone, which belongs to the class of compounds known as ketones. Further oxidation of acetone and other ketones brings about a complete disintegration of the molecule and the formation of acids which contain a smaller number of carbon atoms than the ketone from which they were formed.

In the formation of both aldehydes and ketones by oxidation, the change consists in the removal of two hydrogen atoms; a similarity in structure of the two classes of compounds, and, as a consequence, in their reactions might be expected. Such similarity does exist.

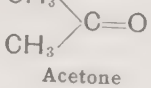
180. Structure of Aldehydes and Ketones.—In the determination of the structure of these substances the manner in which the oxygen atom is linked to carbon is first to be examined. These substances do not show the properties of alcohols or acids, and therefore do not contain a hydroxyl group. The composition of the compounds formed when aldehydes and ketones are treated with phosphorus pentachloride furnishes positive information which leads to an understanding of the structure of members of these classes. The equations for the reactions in the two cases are:

$$C_2H_4O + PCl_5 = C_2H_4Cl_2 + POCl_3$$
$$C_3H_6O + PCl_5 = C_3H_6Cl_2 + POCl_3$$

In both cases one atom of oxygen is replaced by two atoms of chlorine. It is evident from this that the oxygen is not present in the compounds in the form of a hydroxyl group, for in this case the oxygen is joined to carbon by a single bond (C—O—H) and when replaced by chlorine but one atom of the latter can remain in combination with carbon. Further, in the replacement of hydroxyl oxygen by chlorine, hydrogen is simultaneously removed. As in the reactions given above a single oxygen atom is replaced by two chlorine atoms, it seems most probable that the former is held in combination with carbon by two bonds in both aldehydes and ketones, and that these substances contain the *carbonyl group* (C=O). Granted this as true, the structure of aldehyde and acetone can be expressed by the following formulas:

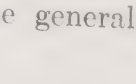


Aldehyde

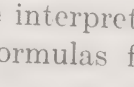


Acetone

It will be shown in the detailed discussion of these compounds that their properties can best be interpreted through the use of these formulas. The general formulas for members of these classes are:



Aldehydes

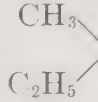


Ketones

The relation between aldehydes and ketones is clear when their structure is expressed in this way. They are alike in containing a carbonyl group; they differ in that aldehydes contain one radical and one hydrogen united to this group, while in the case of ketones two radicals are present. It appears from the formulas that the two classes of compounds should be considered as members of the same homologous series since they bear to each other a relation similar to that between formic and acetic acids (H.COOH and CH_3.COOH). As some characteristic reactions of aldehydes which are not shown by ketones are brought about as the result of the presence in aldehydes of the hydrogen atom in combination with the carbonyl group, compounds which

contain the group $C{=}O$ are treated as a class by themselves. In the study of the properties of aldehydes and ketones, the student should continually keep in mind the relation between the two classes of compounds which has been pointed out.

181. Nomenclature of Aldehydes and Ketones.—The aldehydes are usually named from the acids which they yield on oxidation, thus CH_3.CHO is acetic aldehyde or acetaldehyde, as it is converted by oxidizing agents into acetic acid. In the Geneva system of nomenclature the name of an aldehyde is formed by adding the syllable *al* to the name of the hydrocarbon which contains the same number of carbon atoms as the aldehyde. According to this system acetaldehyde is called ethanal.

The name of a ketone is determined by the radicals which are in combination with the carbonyl group. Thus, the substance with the structure  is called methyl ethyl ketone. The names of ketones, according to the Geneva system, are formed by adding the termination *one* to the name of the hydrocarbon which contains the same number of carbon atoms as the ketone. A number is added to express the position of the carbon of the carbonyl group in relation to the end carbon atom of the chain; thus, diethyl ketone, $CH_3CH_2.CO.CH_2CH_3$, is pentanone-3.

Aldehydes

182. Formaldehyde, H.CHO, is the simplest aldehyde. It is a gas, which is soluble in water, and has a powerful, irritating odor. It can be condensed to a liquid that boils at $-21°$.

Preparation and Uses.—Formaldehyde is formed as the result of the oxidation of methyl alcohol. It is usually prepared by passing a mixture of air and the vapor of methyl alcohol over heated copper. The mixture is obtained by drawing air through the alcohol which is heated to 40° to 50°. After the reaction begins, sufficient heat is evolved as the result of the oxidation to keep the copper, which is conveniently in the form of a spiral of gauze, in a glowing condition. The gases produced are condensed, and a liquid is formed which contains water, methyl alcohol, and formaldehyde. By proper regulation of the process a product can be obtained which contains 40 per cent aldehyde. Such a solution is sold under the name "formalin." It is used as a disinfectant and food preservative, and in the manufacture of certain dyes and synthetic resins. Anatomical specimens may be preserved by keeping them in a solution of formaldehyde. As the aldehyde hardens albuminous substances, it is used in the preparation of tissues in histological work, and as it converts gelatin into a hard insoluble substance, it is frequently used to harden the films on photographic plates.

Chemical Properties—Oxidation.—Formaldehyde is readily oxidized, formic acid and carbon dioxide being formed. When a few drops of a solution containing the aldehyde are added to an ammoniacal solution of silver nitrate, the metal is deposited in the form of a mirror on the sides of the containing vessel. It also reduces the salts of other metals to the metallic condition; for example, a solution of mercuric chloride is reduced to mercurous chloride, and finally to mercury.

In dilute alkaline solution, formaldehyde is oxidized quantitatively by hydrogen peroxide to a formate. The percentage of formaldehyde in commercial formalin can be determined through the use of this reaction, which is represented by the following equation:

$$H.CHO + NaOH + H_2O_2 = H.COONa + 2H_2O$$

An excess of hydrogen peroxide and of a solution of sodium hydroxide of known strength is added to the dilute solution of formalin. The excess of alkali is determined by titration with an acid, and from the amount of sodium hydroxide used in the reaction the weight of aldehyde can be calculated.

Reduction.—Formaldehyde can be reduced by nascent hydrogen to methyl alcohol:

$$H.CHO + 2H = CH_3.OH$$

As all aldehydes take part in a similar reaction it is possible to pass readily from an aldehyde to an alcohol by reduction.

Reaction with Ammonia.—When an aqueous solution of formaldehyde is treated with ammonia, reaction takes place with the formation of a substance of complex structure possessing weakly basic properties, called hexamethylenetetramine:

$$6H.CHO + 4NH_3 = (CH_2)_6N_4 + 6H_2O$$

The compound is used as a medicine under the name "methenamine." The action of this aldehyde with ammonia is unique, as other substances of this class form well-characterized addition products which consist of one molecule of each constituent.

With Sodium Hydroxide.—In aqueous solution in the presence of sodium hydroxide, formaldehyde reacts with water, and formic acid and methyl alcohol are produced:

$$2HCHO + H_2O = CH_3OH + H.COOH$$

In this reaction, also, formaldehyde differs from its homologues, which are converted into resin-like substances by alkalies.

Polymerization of formaldehyde takes place with great readiness. The liquid aldehyde slowly polymerizes at its boiling point (−21°). When an aqueous solution is evaporated over concentrated sulphuric acid or by heat, only a part of the aldehyde escapes as a gas; the rest is left as a white crystalline mass, called *paraformaldehyde,* which melts at 63°. It is sold in the form of tablets or candles under the name "paraform," and is used for disinfecting purposes, as it serves as a convenient source of formaldehyde.

When a dilute aqueous solution of formaldehyde, which is saturated with calcium hydroxide, is allowed to stand for several days, polymerization of the aldehyde takes place and a mixture

of substances, called *formose*, is obtained; the product shows the characteristic reactions of the sugars. From this mixture Emil Fischer isolated *fructose*, a sugar that occurs in nature. The view has been put forward that formaldehyde plays an important part in the building up in plants of the carbohydrates, such as sugar, starch, and cellulose. Plants build up these substances from water and the carbon dioxide in the air. It seems probable that the process consists in the reduction to formaldehyde of carbon dioxide in the presence of water, sunlight, and the chlorophyll in leaves, and that the aldehyde then undergoes polymerization with the production of carbohydrates. The hypothetical reactions may be represented by the following equations:

$$CO_2 + H_2O = H.CHO + O_2$$

$$6H.CHO = C_6H_{12}O_6$$

183. Tests for Formaldehyde.—As formaldehyde was formerly much used as a preservative, many special tests have been devised for its detection when present in minute quantities. One of the simplest is that employed in the investigation of the presence of formaldehyde in milk. The test is carried out by diluting the milk with an equal volume of water, adding a few drops of a solution of ferric chloride, and pouring concentrated sulphuric acid slowly into the mixture so that two layers are formed. If formaldehyde is present, a violet ring forms at the juncture of the liquids when the vessel containing them is immersed in hot water. The test will show the presence of 1 part of formaldehyde in 200,000 parts of milk. The production of the color is the result of a reaction between the aldehyde and a constituent of the milk. Any solution may be tested for the aldehyde by mixing it with pure milk and proceeding in the manner described. Other color reactions are frequently used.

A convenient test which may be used to detect small quantities of formaldehyde is made as follows: To about 1 c.c. of the solution of the aldehyde which has been diluted to such a concentration that its odor is barely perceptible, is added one drop of a 0.5 per cent aqueous solution of resorcinol (**534**). The mixture so prepared is poured slowly down the side of a test tube containing about 5 c.c. of concentrated sulphuric acid in such a way that the two liquids do not mix. A red ring soon appears at the juncture of the two liquids, and a white flocculent precipitate, which changes to red, forms in the aqueous layer.

184. Acetaldehyde, $CH_3.CHO$, is a typical member of the homologous series of aldehydes, which can be prepared from the saturated alcohols. The methods by which it may be formed and its reactions with other substances are more representative of the group than those of formaldehyde. It will be recalled that formic acid, the first member of the fatty acid series, differs markedly in some of its reactions from acetic acid and the other members of the series. The same relations have been observed in the case of the first members of other homologous series.

Acetaldehyde is a liquid which is miscible with water in all proportions, and possesses a markedly characteristic odor. It boils at 20.2°, melts at −123.5°, and has the specific gravity 0.781 at $\frac{25°}{4°}$.

Preparation.—It is prepared by oxidizing ethyl alcohol. A mixture of alcohol, sulphuric acid, and water is allowed to drop slowly on powdered potassium dichromate contained in a flask provided with a condenser. Reaction soon takes place, and a distillate is obtained which contains aldehyde, alcohol, and small quantities of other substances. On slow redistillation, care being taken to collect only the part which boils below 35°, aldehyde containing only a small amount of water is obtained. The final purification is effected by distillation, after drying with calcium chloride.

Formation.—Aldehyde is formed *when a salt of acetic acid is heated with a formate:*

$$\begin{matrix} CH_3|COONa \\ HCO|ONa \end{matrix} = CH_3.CHO + Na_2CO_3$$

The structure assigned to formic acid, $H—\overset{\overset{O}{\|}}{C}—OH$, indicates that it contains an aldehyde group. Some of its reactions are in accord with this view of its structure. It will be recalled that it is oxidized with great ease. It reduces an ammoniacal solution of silver nitrate, and thus takes part in a reaction which is of great value in the identification of aldehydes. The reaction which takes place when a formate is heated with a salt of acetic acid, is one of importance, on account of the fact that it is an example of a general reaction which can be applied in the preparation of other members of this class. When the salt of an acid

is heated with a formate, the corresponding aldehyde is obtained. Calcium salts are commonly used, as the yield of aldehyde is greater than that obtained when salts of the alkali metals are employed.

Aldehyde is formed *by the direct removal of hydrogen from alcohol.* This can be effected by passing the vapor of alcohol over finely divided copper obtained by the reduction of copper oxide. When the temperature is maintained at 250° to 400° direct decomposition of the alcohol takes place according to the equation

$$C_2H_6O = C_2H_4O + H_2.$$

When palladium black is brought into contact with alcohol at room temperature in the absence of oxygen, a part of the alcohol is converted into aldehyde, and palladium hydride is formed. If oxygen is now admitted the hydride is converted into water. This fact indicates that in the catalytic oxidation of alcohol to aldehyde by oxygen the process consists in dehydrogenation, followed by the oxidation of the hydrogen withdrawn.

Manufacture.—Aldehyde is manufactured in large quantities from acetylene (**53**). The gas is passed into a solution of dilute sulphuric acid in which mercuric oxide is kept in suspension by vigorous stirring. Under these conditions acetylene unites with water and aldehyde is formed. The gas is passed through the mixture at such a rate that only a part of it reacts; the rest sweeps along with it the aldehyde, which is separated by passing the gases through a refrigerating system. The liquid yields, on rectification, aldehyde of 99.9 per cent purity.

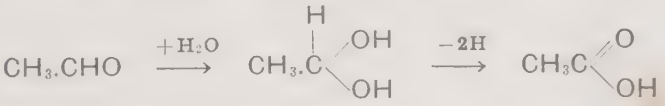
185. The reactions of aldehyde are, in general, typical of the substances which contain the group $-\overset{H}{\underset{|}{C}}=O$. They are best explained on the assumption that aldehyde contains a group of this configuration and serve to strengthen the conclusion arrived at from the study of the action of phosphorus pentachloride upon aldehyde.

With Oxidizing Agents.—The hydrogen atom in combination with the carbonyl group (C=O) can be readily oxidized. When a solution containing aldehyde is mixed with an ammoniacal solution of silver nitrate, a silver mirror is formed and the alde-

hyde is converted into acetic acid. Gentle heat and the presence of a few drops of a solution of potassium hydroxide facilitate the reduction of the silver salt. The caustic alkali should be added to the ammoniacal solution just before use, as such a solution deposits, on standing in the presence of sodium or potassium hydroxide, a substance which may suddenly undergo decomposition with explosive violence.

The manufacture of acetic acid from aldehyde by oxidation with air, in the presence of a catalyst, has already been noted (**109**). The aldehyde is readily oxidized electrolytically when it is placed in the anode compartment of a cell. This method of oxidizing organic compounds is efficient and involves the formation of no by-products from the oxidizing agent; it is being studied carefully and has been applied to the preparation of a number of organic compounds; in all probability its use will be extended.

When an aqueous solution of aldehyde is treated with palladium black in the absence of free oxygen, acetic acid and palladium hydride are formed. The mechanism of the reaction is indicated by the following formulas:

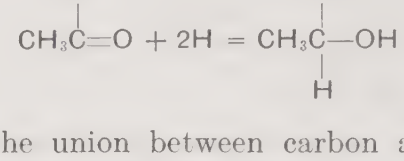


If a supply of oxygen is furnished, the palladium hydride first formed is constantly changed into palladium and water, and the conversion of the aldehyde to acid proceeds. These facts explain the action of the catalyst in oxidation processes of this kind.

Addition Reactions.—The most characteristic reactions of aldehydes are those in which they form addition products with other substances, and those in which polymers are formed as the result of the direct combination of two or more molecules of the aldehyde. These reactions are the result of the presence of the carbonyl group (C=O) in aldehydes.

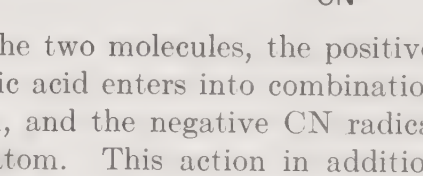
With Hydrogen.—Aldehyde is reduced to alcohol when treated in aqueous solution with sodium amalgam, or when it is passed with hydrogen over reduced nickel heated to 180°. The reduction consists in the addition of two hydrogen atoms to the mole-

cule. This addition is made possible by the breaking of the double bond between the carbon and oxygen atoms:



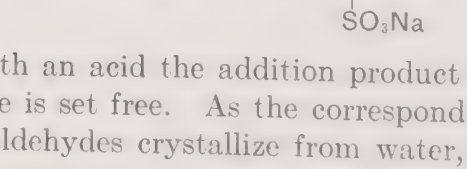
The nature of the union between carbon and oxygen in the carbonyl group in aldehydes resembles somewhat that between the unsaturated carbon atoms in ethylene. In both cases saturated addition products can be formed as the result of the addition of other atoms or molecules.

With Hydrocyanic Acid.—Aldehyde and hydrocyanic acid unite and form a substance which has been shown to be the nitrile of α-hydroxypropionic acid. The addition must, therefore, take place according to the equation



In the union of the two molecules, the positive hydrogen atom of the hydrocyanic acid enters into combination with the negative oxygen atom, and the negative CN radical with the more positive carbon atom. This action in addition is an example of a general principle which applies to many such reactions. When two molecules interact there is a tendency for the reaction to take place in such a way that the more positive part of one unites with and tends to neutralize the more negative part of the other.

With Sodium Bisulphite.—When aldehyde is shaken with a saturated solution of sodium hydrogen sulphite, addition takes place and a crystalline compound is obtained:



When heated with an acid the addition product is decomposed and the aldehyde is set free. As the corresponding derivatives of many other aldehydes crystallize from water, the formation

of such derivatives is frequently taken advantage of in the isolation of aldehydes and in their purification from other substances.

With Ammonia.—Aldehyde combines directly with ammonia to form a compound called aldehyde ammonia. It is usually prepared by passing gaseous ammonia and the vapor of aldehyde into dry ether, which is kept cold. The compound separates as well-formed crystals. Addition takes place according to the equation

$$CH_3C(H)=O + NH_3 = CH_3C(H)(NH_2)-O-H.$$

As aldehyde is formed when aldehyde ammonia is warmed with a dilute acid, the substance can be used in the preparation of pure aldehyde. Aldehyde ammonia has recently been used as an accelerator in the vulcanization of rubber.

With Alkyl-magnesium Halides.—Aldehydes form addition products with alkyl-magnesium halides, from which secondary alcohols may be obtained by decomposition with water (**85**).

186. *Oximes and Hydrazones.*—Aldehydes enter into important reactions of another type. The reaction *with hydroxylamine* is an example. When an aldehyde is warmed with an aqueous solution of this reagent a substance is formed which belongs to the class known as *oximes*. Acetaldehyde gives *acetaldoxime:*

$$CH_3C(H):O + H_2N.OH = CH_3C(H):N.OH + H_2O$$

As many oximes have well-defined physical properties they are of service in the identification of aldehydes. The oximes are hydrolyzed when boiled with dilute hydrochloric acid.

A reaction of similar nature takes place between aldehydes and *hydrazine:*

$$CH_3C(H):O + H_2N.NH_2 = CH_3C(H):N.NH_2 + H_2O$$

The compounds formed, called *hydrazones*, can be hydrolyzed by boiling with a dilute acid. In the identification of aldehydes, the physical properties of the phenylhydrazone prepared from the aldehyde and *phenylhydrazine*, $C_6H_5HN.NH_2$, are frequently

determined. The reaction in this case is analogous to that with hydrazine:

$$CH_3\overset{H}{\overset{|}{C}}{:}O + H_2N.NHC_6H_5 = CH_3\overset{H}{\overset{|}{C}}{:}N.NHC_6H_5 + H_2O$$

187. Substances called *acetals* are prepared by a reaction which resembles somewhat those just described. When acetaldehyde is heated *with alcohol* in the presence of acetic acid or a small amount of hydrogen chloride or sulphuric acid, acetal is formed:

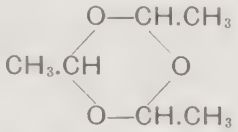
$$CH_3\overset{H}{\overset{|}{C}}{:}O + \begin{matrix}HOC_2H_5\\HOC_2H_5\end{matrix} = CH_3\overset{H}{\overset{|}{C}}\begin{matrix}OC_2H_5\\OC_2H_5\end{matrix} + H_2O$$

The methods of preparation of acetals recall that of esters, but the compounds more closely resemble ethers in chemical properties. They are unaffected by alkalies, but are readily hydrolyzed by boiling with acids. Acetals are frequently used in syntheses in the place of the more active aldehydes. The substances formed from the two classes of substances in such syntheses are the same.

188. The polymerization of aldehyde is readily effected. When aldehyde is warmed with a strong *solution of an alkali*, the solution becomes yellow in color and a resin-like substance precipitates. This is called *aldehyde resin*. Its chemical composition is not known. It is probably formed as the result of polymerization and dehydration of aldehyde. It will be remembered that formaldehyde is not converted into a resin in this way. The reaction is, however, characteristic of other aldehydes.

In the presence of acids the polymerization of aldehydes yields substances of a different nature. When aldehyde is treated with a drop of concentrated sulphuric acid, polymerization immediately takes place with the evolution of sufficient heat to cause violent boiling. The product formed, called *paraldehyde*, is a colorless liquid with characteristic odor, which boils at 124°, and after solidification melts at 10.5°. It is soluble in about eight volumes of water and has the specific gravity 0.994 at $\frac{20°}{4°}$. The molecular weight of paraldehyde, calculated from its vapor density, corresponds to that expressed by the formula $(C_2H_4O)_3$. Paraldehyde shows none of the reactions characteristic of aldehydes. It does not, therefore, contain the aldehyde group. As it is converted into aldehyde when heated

with dilute solutions of mineral acids, it is probable that in its formation the addition of the three molecules of aldehyde into one molecule is effected through the oxygen atoms, and not through the union of carbon atoms with each other. The structure assigned to paraldehyde is

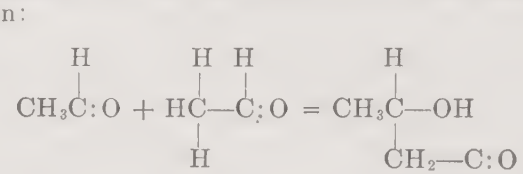


This view is based on the fact that the study of many compounds has shown that the breaking of the bond between two carbon atoms is, in most cases, accomplished with difficulty, whereas compounds in which carbon atoms are united through an oxygen atom are decomposed with more or less ease. For example, hydrocarbons and the alkyl radicals which they contain are very stable, whereas esters, ethers, and other compounds in which oxygen serves as a link in holding the atoms together can be decomposed by various reagents. It is important to note that in these decompositions the bond between oxygen and carbon is broken and not that between two carbon atoms.

If the polymerization of acetaldehyde is brought about by acids at a low temperature, a solid polymer, called *metaldehyde*, is formed. It separates in fine needles when a trace of hydrogen chloride, sulphur dioxide, or dilute sulphuric acid is added to well-cooled aldehyde. Metaldehyde is insoluble in water, sublimes with partial decomposition into aldehyde when rapidly heated, and shows none of the reactions characteristic of aldehydes. Its molecular weight is not known with certainty.

The polymerization of aldehydes is a reaction which, in all probability, plays an important part in life processes. The view of the rôle of formaldehyde in the growth of plants has already been mentioned. Experiments on protoplasm indicate that aldehydes are involved in the building up of cells. Living cells reduce an ammoniacal solution of silver nitrate and show other reactions characteristic of aldehydes. Dead cells, on the other hand, show none of these reactions. It is of interest to note in this connection that hydroxylamine, phenylhydrazine, and other substances which react readily with aldehydes are powerful poisons, especially for the lower organisms.

189. *Aldol.*—When acetaldehyde is treated with a dilute solution of a alkali or certain salts, such as sodium acetate and zinc chloride, a polymer formed, which consists of two molecules of aldehyde in combination wit each other. This substance, called *aldol*, is a liquid which boils witho decomposition under diminished pressure and readily undergoes furth polymerization. Aldol shows the reactions which are characteristic of ald hydes and can be converted by oxidation into β-hydroxybutyric aci These facts are evidence that aldol is the aldehyde of this acid. The unio of the aldehyde molecules to form aldol is, therefore, best represented by th following equation:



If this view is correct—and the properties of aldol are in accord with th structure given—the union takes place in a way which is entirely analogou to that between aldehyde and hydrocyanic acid, ammonia, or sodium hydro gen sulphite. In all these cases one hydrogen atom enters into combinatio with the oxygen of the carbonyl group, and the rest of the compound unite with the carbon atom of this group. According to this view aldol contain an aldehyde group, and, as a consequence, its reactions, which are those o an aldehyde, are readily understood. It also contains an alcohol radica these facts were taken into account when the substance was called aldol— *ald*(dehyde-alcoh)*ol*.

Aldol loses water when heated with a solution of sodium acetate and form crotonic aldehyde:

$$CH_3.CHOH.CH_2.CHO = CH_3.CH:CH.CHO + H_2O$$

Substances of these types are readily obtained from aldehydes. As a conse quence the so-called aldol condensation is frequently made use of in syntheti organic chemistry. By *condensation* is meant the union of two or more o the same or different molecules, with or without the elimination of water o some other inorganic compound. The term is usually restricted to includ only those reactions in which carbon unites with carbon, and compounds ar formed which cannot be readily decomposed into the substance or sub stances from which they were prepared.

A synthesis of butadiene from which a rubber was prepared by polymeriza tion, has been effected from aldol; the steps in the process are indicated by the following formulas:

$$CH_3.CHOHCH_2CHO \xrightarrow{H} CH_3.CHOH.CH_2.CH_2OH \xrightarrow{HCl}$$

$$CH_3.CHCl.CH_2.CH_2Cl \xrightarrow{-HCl} CH_2{=}CH.CH{=}CH$$

While this synthesis lacks industrial significance at present, it is of interest in that it makes it possible to synthesize the rubber from coal, through the preparation of calcium carbide, acetylene and acetaldehyde. These latter steps in the process have been put on an industrial basis.

In the presence of aluminium or sodium ethylate two molecules of aldehyde unite and ethyl acetate is formed:

$$CH_3\overset{H}{C}{:}O + H{-}\overset{O}{C}CH_3 = CH_3\overset{H}{\underset{H}{C}}{-}O{-}\overset{O}{C}CH_3$$

The difference between this method of union and that which takes place when aldol is formed should be noted. The two reactions show the selective action of different catalysts in labilizing different bonds in the same compound.

190. Homologues of Acetaldehyde.—A number of members of a homologous series of aldehydes are known. The lower members (up to $C_{11}H_{22}O$) are liquids, which are lighter than water, distill without decomposition, and possess a more or less disagreeable odor. The lowest members are readily soluble in water, but the solubility rapidly decreases as the number of carbon atoms in the molecule increases. The higher aldehydes are colorless, waxy solids.

191. Properties of Aldehydes of Analytical Significance.—Two of the reactions of aldehyde which have been described are much used in the identification of members of this class of compounds, namely, the formation of a mirror when an ammoniacal solution of silver nitrate is gently warmed with an aldehyde, and the change of the latter to a resin when heated with a strong solution of a caustic alkali. If these reactions take place when a substance is treated as described, there is a strong probability that it is an aldehyde. Compounds other than aldehydes, however, reduce an ammoniacal solution of silver salts, and other tests should be applied in addition to the ones just given. When an aqueous solution of rosaniline, which is a red dye, is treated with a saturated solution of sulphur dioxide in water, the color is destroyed. The colorless solution, known as *Schiff's reagent*, is of great value in testing for aldehydes. When a few drops of an aldehyde are added to about 5 c.c. of the reagent, a red-violet color appears within a few seconds.

Aldehydes reduce an alkaline solution of a cupric salt to cuprous oxide. The reagent used is called *Fehling's solution* (**324**). It is prepared by adding copper sulphate to a solution which contains sodium hydroxide and Rochelle salt (sodium potassium tartrate), $(CHOH.COO)_2KNa$. In the presence of the tartrate, copper hydroxide is not precipitated, and a clear, dark-blue solution is obtained. When an aldehyde is warmed with Fehling's solution, cuprous oxide is formed as a precipitate, which is usually red. As certain substitution products of ketones (**377**) reduce Fehling's solution, the test does not serve to identify aldehydes positively. It is however of service, and is much used in the study of carbohydrates, many of which contain aldehyde groups.

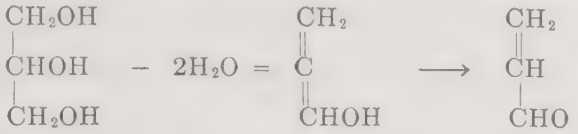
Unsaturated Aldehydes

192. The chemistry of the unsaturated aldehydes resembles closely that of acetaldehyde. They may be prepared by the oxidation of unsaturated primary alcohols, and by the conversion of saturated aldehydes into unsaturated compounds by the application of the methods usually employed to establish a double bond in a compound. Certain members of this class occur in the so-called *essential oils*—the volatile liquids which give the characteristic odors to plants. The composition of a number of these oils will be given later.

193. Acrylic aldehyde, $CH_2{=}CH.CHO$, is the unsaturated aldehyde which contains the smallest number of carbon atoms. On account of the fact that it has a disagreeable, penetrating odor and affects the eyes strongly producing a copious flow of tears, it was originally named "acrolein" (from *acer*, sharp; and *oleum*, oil) and is still often called by this name. This property of acrolein led to its use as a war gas. It was found not only to possess the lachrymatory properties required of a "tear gas," but to have toxic properties. It was used by the French in hand grenades.

Acrolein is a colorless liquid, which boils 52.5°. It can be prepared by the oxidation of allyl alcohol, $CH_2{=}CH.CH_2OH$, but is obtained more readily by the removal of water from glycerol. The dehydration is best effected by heating glycerol with acid potassium sulphate.

194. The removal of two molecules of water from glycerol should yield an alcohol with two double bonds if the reaction takes place normally:



As acrolein is obtained, however, it is evident that if such an alcohol is formed it immediately undergoes a rearrangement which results in the formation of the aldehyde. The relation between the two formulas is similar to that between the formulas of vinyl alcohol and acetaldehyde: $CH_2{=}CHOH \longrightarrow CH_3.CHO$.

195. Acrolein is formed when fats and oils, which it will be remembered are esters of glycerol, are heated to a high temperature. The pungent odor produced when a tallow candle is extinguished is probably due to the formation of acrolein. The reactions of acrolein are in accord with the structure assigned to it. It can be reduced to allyl alcohol and oxidized to acrylic acid. It reduces an ammoniacal solution of silver salts, is converted into a resin by alkalies, and polymerizes with great readiness.

The presence of the double bond is shown by the fact that acrolein unites with two atoms of bromine and forms a compound of the structure $CH_2Br.CHBr.CHO$.

196. The presence of the double bond modifies to some extent the reactions of the aldehyde group in acrolein; it does not unite with ammonia to form an addition product similar to that formed by acetaldehyde and most other saturated aldehydes. The union of acrolein with ammonia takes place according to the equation

$$2C_3H_4O + NH_3 = C_6H_9NO + H_2O.$$

Acrolein ammonia is an amorphous basic substance which resembles glue in physical properties.

The presence of the aldehyde group in acrolein modifies the reactions of the doubly linked carbon atoms. Acrolein unites with two molecules of sodium bisulphite. As but one molecule is removed when the addition product is heated with acids, it is probable that the other is added to the compound as the result of the breaking of the double bond. Unsaturated hydrocarbons do not unite with acid sulphites.

197. Geranial, also called *citral*, is an example of an aldehyde which contains two double bonds. It is an important constituent of various essential oils, among which are those derived from lemons, geraniums, roses, and orange rind. It is a liquid, which possesses an agreeable odor and boils at 110° to 112° under a pressure of 12 mm. An interpretation of the methods

used in its synthesis and of its reactions leads to the conclusion that i structure is represented by the following formula:

$$(CH_3)_2C{:}CH.CH_2.CH_2.C(CH_3){:}CH.CHO$$

Ketones

198. Acetone, $(CH_3)_2CO$, is the first member of the series c ketones which contain saturated alkyl groups. It is a colorles liquid, which has the specific gravity 0.7915 at $\frac{20°}{4°}$ and boils a 56.1°; it has a characteristic odor and is miscible with wate Acetone occurs in small quantities in normal urine, but th amount is greatly increased in severe cases of diabetes. It i a good solvent for resins, gums, and many organic compounds and is used in varnish removers. It is also used in the prepara tion of chloroform, iodoform, sulphonal, and other substance used in pharmacy.

Preparation.—Acetone is obtained as the result of the *distilla tion of wood* (**61**). It is usually prepared by the destructiv distillation of calcium acetate:

$$\begin{matrix} CH_3COO \\ CH_3COO \end{matrix}\!\!>\!Ca = \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CO + CaCO_3$$

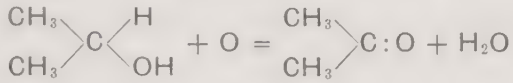
The acetone prepared in this way contains impurities from whic it may be freed by treatment with acid sodium sulphite. Pur acetone is liberated from the crystalline addition product formed by heating the latter with a solution of sodium carbonate. Wate is removed by fractional distillation, and the acetone is finall dried over calcium chloride and distilled.

The demand for acetone was so great during the World Wa that new industrial methods for its preparation were develope and are now in use. In one of these acetone is produced by th *fermentation of glucose* with *Bacillus butylicus* at about 40° i the absence of air. The fermentation also yields *n*-butyl alcohol which is formed in the proportion of two volumes to one o acetone.

Large quantities of acetone are made directly from *aceti acid* by heating it at 485° in the presence of calcium carbonat which serves as a catalyst:

$$2CH_3COOH = (CH_3)_2CO + CO_2 + H_2O$$

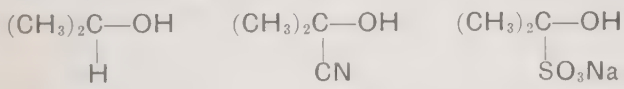
The formation of acetone as the result of the *oxidation of isopropyl alcohol* is of interest, as it throws light on the relation which exists between the structures of these compounds:



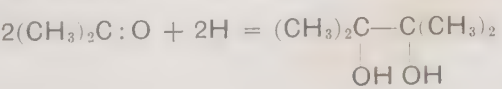
In the use of this reaction in the preparation of acetone for industrial purposes, a mixture of air and the vapor of isopropyl alcohol is passed over heated brass gauze. The ketone is also formed when isopropyl alcohol is heated in the presence of finely divided copper. A decomposition takes place analogous to that by which primary alcohols yield aldehydes:

$$(CH_3)_2CHOH = (CH_3)_2CO + H_2$$

199. Reactions of Acetone.—Many of the reactions of acetone are determined by the presence in it of a carbonyl group. It forms *addition products* with hydrogen, hydrocyanic acid, and sodium hydrogen sulphite, the structures of which are represented by the following formulas:



It does not form, however, an addition product with ammonia similar to that derived from aldehyde, but complex condensation products. When reduced by nascent hydrogen generated by the action of sodium amalgam on water, addition takes place as indicated above, and isopropyl alcohol is formed, but at the same time a dihydroxy alcohol, which contains six carbon atoms, is produced in appreciable quantities. This substance, called *pinacol*, is the first member of a series of such alcohols which are formed by the reduction of ketones. The equation for the reaction in the case of acetone is as follows:



Ketones resemble aldehydes in that they form *oximes* and *hydrazones*, which are useful in the identification of members of this class of compounds. The structure of the compounds

derived from acetone and hydroxylamine and phenylhydrazine are respectively

$$(CH_3)_2C{=}NOH \quad \text{and} \quad (CH_3)_2C{=}N.NHC_6H_5.$$

200. Acetone does not polymerize. It does, however, undergo *condensation* with loss of water, when treated with certain dehydrating reagents. When it is saturated with dry hydrogen chloride and allowed to stand for some time, a mixture of two unsaturated ketones, called *mesityl oxide* and *phorone*, is formed. A study of the reactions of these substances leads to the constitutions expressed by the following formulas:

$$\underset{\text{Mesityl oxide}}{(CH_3)_2C{=}CH.CO.CH_3} \qquad \underset{\text{Phorone}}{(CH_3)_2C{=}CH.CO.CH{=}C(CH_3)_2}$$

The condensation in these cases resembles that in which crotonic aldehyde is formed from acetaldehyde. In the three cases the oxygen of a carbonyl group unites with two hydrogen atoms of a methyl group, and water and an unsaturated compound are formed.

201. Acetone reacts readily with *chlorine* and *bromine*. The substitution products formed are characterized by their exceedingly irritating action on the eyes. Bromoacetone was used by the Germans as a tear gas.

When acetone is treated with *phosphorus pentachloride* the oxygen atom is replaced by two halogen atoms. An unsaturated halogen compound is also formed as the result of the elimination of hydrogen chloride:

$$(CH_3)_2CO + PCl_5 = (CH_3)_2CCl_2 + POCl_3$$

$$CH_3CCl_2CH_3 = CH_2{:}CCl.CH_3 + HCl$$

202. Homologues of Acetone.—These compounds may be prepared by the *distillation of the calcium salts of the fatty acids*. If a mixture of the salts of two acids is used, a ketone is obtained which contains the two radicals present in the acids used. Thus calcium acetate and calcium propionate yield methyl ethyl ketone:

$$\begin{matrix}(CH_3COO)_2Ca \\ (C_2H_5COO)_2Ca\end{matrix} = 2\begin{matrix}CH_3 \\ C_2H_5\end{matrix}\!\!>\!CO + 2CaCO_3$$

Acetone and diethyl ketone are obtained at the same time as the result of the decomposition of the acetate and propionate.

Ketones can be prepared by the *replacement of the halogen atom of an acyl halide* (*e.g.*, CH_3COCl) by an alkyl group. This

replacement can be effected as the result of the action of certain organic compounds which contain metals. The zinc alkyls or alkyl-magnesium halides are generally used. Methyl ethyl ketone can be prepared in this way from acetyl chloride and ethyl-magnesium iodide:

$$2CH_3COCl + 2C_2H_5MgI = 2CH_3COC_2H_5 + MgCl_2 + MgI_2$$

An intermediate product is formed as the result of the addition of the acid chloride and alkyl-magnesium halide, the addition taking place in a way similar to that which has been explained (**85**). This synthetic method is an important one, as it serves to replace a halogen atom in an acyl halide by an alkyl group.

203. *Pinacol, Pinacolin.*—Ketones which contain a tertiary alkyl group are formed as the result of the elimination of water from pinacols. When pinacol is heated with an aqueous solution of an acid, it loses water and forms a ketone, named *pinacolin*, which is the first member of a series of substances known as pinacolins. In the transformation a molecular rearrangement evidently takes place. The probable course of the reaction is expressed by the following formulas:

$$(CH_3)_2C(OH) - C(OH)(CH_3)_2 \xrightarrow{-H_2O} (CH_3)_2C\langle O \rangle C(CH_3)_2 \longrightarrow (CH_3)_3C - C(=O) - CH_3$$

Pinacol — Pinacolin

The conclusion that pinacolin has the constitution assigned to it here has been reached as the result of the study of the reactions of the compound. Its formation as the result of the elimination of water from pinacol would lead to the view that it is an ether, and has the structure represented by the middle formula in the series above. Pinacolin, however, shows the reactions which are characteristic of ketones. The intermediate product in the transformation of a pinacol to a pinacolin has been isolated in certain cases.

204. The *reactions of the ketones* are similar to those of acetone. Most ketones, however, which do not contain the group CH_3CO do not unite with sodium hydrogen sulphite.

The products formed as the result of the oxidation of ketones often serve as a guide in the determination of their structure. The compounds break at the carbonyl group and acids are formed. Thus, ethyl amyl ketone breaks at the points indicated in the following formulas:

$$CH_3CH_2|COC_5H_{11} \qquad CH_3CH_2CO|C_5H_{11}$$

If the ethyl group is eliminated, acetic acid, CH_3COOH, and caproic acid, $C_5H_{11}COOH$, are obtained. If decomposition takes place according to the second formula, propionic acid, $CH_3CH_2.COOH$, and valeric acid, C_4H_9COOH, result. The oxidation of most ketones takes place, in large part, in such a way that the smaller radical remains in combination with the carbonyl group. The position of the carbonyl group in ketones can, therefore, be frequently determined by oxidation. The structure of the ketone which is the chief constituent of the *oil of rue* has been determined in this way. As it yields acetic acid and pelargonic acid, $C_8H_{17}COOH$, on oxidation, it is methyl nonyl ketone, $CH_3COC_9H_{19}$.

The physical properties of the higher ketones resemble closely those of the aldehydes. Ketones, however, have in general a not unpleasant odor.

205. Reactions of Ketones of Analytical Significance.—In the identification of a substance as a ketone, an oxime or a phenylhydrazone is usually prepared from it. In the case of ketones which contain the CH_3CO group, crystalline addition products with sodium hydrogen sulphite may be formed. As these reactions are shown by aldehydes, the substance must be tested to determine the presence or absence of the CHO group. Ketones do not reduce Fehling's solution or an ammoniacal solution of silver nitrate, and produce a color with Schiff's reagent only after standing some time.

Problems

1. Write equations for reactions by which aldehydes and ketones may be prepared.

2. Summarize in chemical equations: (*a*) the reactions shown by both classes of compounds, and (*b*) the reactions typical of each class.

3. Write equations for reactions by which acetic aldehyde can be converted into (*a*) acetic acid, (*b*) ethyl alcohol, (*c*) *sec.*-butyl alcohol, (*d*) methyl ethyl ketone, (*e*) crotonic acid, (*f*) ethyl acetate, (*g*) $CH_3.CHOH.COOH$.

4. Write equations for reactions by which methyl ethyl ketone may be converted into the following: (*a*) *sec.*-butyl alcohol, (*b*) *tert.*-amyl alcohol, (*c*) $CH_3.CCl_2.C_2H_5$, (*d*) $CH_3.CCl{=}CH.CH_3$, (*e*) $(CH_3)_2C{=}CHCH_3$, (*f*) $CH_3CH{=}CHCH_3$, (*g*) CH_3COOH.

5. (*a*) By what reactions can C_2H_5OH be converted into CH_3CHCl_2; (*b*) isopropyl alcohol into $(CH_3)_2CCl_2$; (*c*) *tert.*-butyl alcohol into $(CH_3)_2CCl.CH_2Cl$?

6. By what reagents could the following be distinguished: (*a*) acrylic aldehyde and propionic aldehyde; (*b*) acetone, butyric aldehyde, and ethyl butyrate; (*c*) pinacolin and isoamyl alcohol; (*d*) mesityl oxide and acrylic aldehyde?

7. How could you separate without the use of distillation the following: (*a*) C_3H_7CHO and C_6H_{14}; (*b*) $(C_2H_5)_2CO$ and $C_2H_5COOC_2H_5$; (*c*) $(C_2H_5)_2O$ and $(C_2H_5)_2CO$?

8. What chemical tests would you apply to show the presence of (*a*) CH_3CHO in C_2H_5OH; (*b*) CH_3OH in C_2H_5OH; (*c*) $(CH_3)_2CO$ in CH_3OH; (*d*) C_2H_5OH in $(C_2H_5)_2O$; (*e*) $(C_2H_5)_2O$ in C_2H_5Br?

CHAPTER XI

AMINES AND AMIDES

206. Amines.—In the discussion of certain organic compounds containing oxygen it was convenient to consider them as derived from water by the replacement of one or both hydrogen atoms by radicals. The relation between alcohols, acids, ethers, anhydrides, and esters was indicated in this way. It was shown that the properties of the compounds so derived, varied with the nature of the radical introduced.

Certain important classes of compounds which contain nitrogen may be considered in the same way as substitution products of ammonia. It will be seen in the case of these compounds, also, that the nature of the group which replaces the hydrogen determines the characteristic chemical properties of the resulting compounds. When an alkyl group is the substituent, the substances are called *amines*. As ammonia contains three hydrogen atoms that may be replaced, three classes of amines are possible and three are known. Thus, the compounds which have the composition represented by the formulas $(CH_3)NH_2$, $(CH_3)_2NH$ and $(CH_3)_3N$ are methylamine, dimethylamine, and trimethylamine, respectively. They are representatives of the classes known as *primary*, *secondary*, and *tertiary* amines.

Substitution products of ammonium hydroxide in which four hydrogen atoms are replaced by alkyl radicals exist and form an interesting class of compounds. Ammonium hydroxide has been isolated at very low temperatures only. When an attempt is made to obtain it under ordinary conditions, it undergoes decomposition spontaneously with the formation of ammonia and water. It probably exists, however, in aqueous solution. When the four hydrogen atoms in the ammonium radical are replaced by alkyl groups an analogous decomposition does not take place; stable compounds result, of which tetramethylammonium hydroxide, $(CH_3)_4N.OH$, is an example. Compounds of this type are known as *quaternary ammonium bases*.

The amines resemble ammonia in chemical properties. Thus they unite with acids and form well-characterized salts; methylamine, for example, combines with hydrochloric acid and forms a salt which is called methylammonium chloride:

$$CH_3NH_2 + HCl = CH_3NH_3Cl$$

The salt is sometimes called methylamine hydrochloride, and its formula is written $CH_3NH_2.HCl$. The replacement of hydrogen in ammonium hydroxide by alkyl groups yields compounds which react with water and form bases much stronger than ammonium hydroxide. The accumulation of radicals in the quaternary ammonium bases results in the production of marked basic properties in these compounds. Tetramethylammonium hydroxide shows about as strong basic properties as potassium hydroxide.

Amines which are derived from bivalent radicals are also known. Ethylenediamine, $\begin{matrix} CH_2NH_2 \\ | \\ CH_2NH_2 \end{matrix}$, is an example of this type. The diamines resemble closely in chemical properties the simple amines.

207. Amides.—The compounds formed by the replacement of hydrogen atoms of ammonia by acyl radicals are called *amides*. Acetamide, $CH_3CO.NH_2$; diacetamide, $(CH_3CO)_2NH$; and triacetamide, $(CH_3CO)_3N$, are examples of the three classes of compounds which exist. Of the amides only those which contain one acyl group will be considered here.

The amides are neutral to indicators and form salts only with the most active inorganic acids. In the presence of a large excess of concentrated hydrochloric acid, acetamide forms the compound $CH_3CONH_2.HCl$, and when it is dissolved in a mixture of alcohol and ether and treated with dry hydrogen chloride, an addition product of the formula $(CH_3CONH_2)_2.HCl$ is formed. These substances are decomposed into their components by water, and the amide is set free. Diacetamide, which contains two acyl radicals, does not form addition products with acids; the ability of ammonia to form a base when it unites with water is completely destroyed as the result of the replacement of the hydrogen atoms by two acyl radicals.

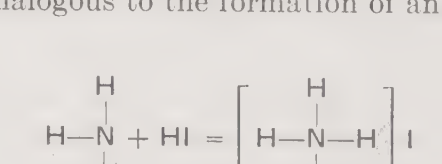
The amides which contain one acyl group may be considered as substitution products of acids formed by the replacement of the hydroxyl by the NH_2 group. When this group occurs in amides it is called the *amido* group. When it is in combination with an alkyl radical, and shows therefore basic properties, it is called the *amino* group to emphasize the relation of the compound in which it is present to the amines.

Amines

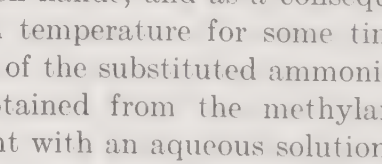
208. Methylamine, CH_3NH_2, is a gas which can be condensed by cooling to a liquid which boils at $-6.5°$. It is very soluble in water; 1,150 volumes of the gas are absorbed by one volume of water at 12.5°. The odor of methylamine resembles closely that of ammonia.

Methylamine is produced in small quantities in the decomposition of nitrogenous organic matter, and is one of the products of the distillation of animal matter and of wood. It occurs in herring brine along with dimethylamine and trimethylamine, and in *Mercurialis perennis*.

Preparation.—It may be prepared by heating methyl iodide with a strong aqueous solution of ammonia in a sealed vessel under pressure:



The reaction is analogous to the formation of an ammonium salt from ammonia:



Addition takes place, however, with the alkyl halide more slowly than with a hydrogen halide, and as a consequence heating the substance at a high temperature for some time is required to effect the formation of the substituted ammonium salt.

The amine is obtained from the methylammonium iodide formed, by treatment with an aqueous solution of a base. The

reaction is analogous to that by which ammonia is liberated from its salt and takes place instantaneously:

$$CH_3NH_3I + KOH = CH_3NH_2 + KI + H_2O$$

Methylamine can also be prepared by passing ammonia and the vapor of methyl alcohol over alumina or other oxides heated to about 300°:

$$CH_3OH + NH_3 = CH_3NH_2 + H_2O$$

209. *Hofmann's Reaction.*—As substitution products of ammonium iodide which contain two, three, and four alkyl groups are obtained along with methylammonium iodide by the action of ammonia on methyl iodide—a fact explained below—methylamine is most readily prepared in the pure condition from acetamide by what is known as Hofmann's reaction. When an amide is treated with bromine and an aqueous solution of sodium hydroxide, the first reaction which takes place consists in the replacement of one of the hydrogen atoms in the amido group by bromine. The equation for the reaction in the case of acetamide is as follows:

$$CH_3CONH_2 + Br_2 + NaOH = CH_3CONHBr + NaBr + H_2O$$

The exchange of hydrogen for bromine in this case is accomplished in a way which is identical with that used to bring about a similar exchange in the case of ammonia itself. The student will recall the fact that when ammonia is treated with a solution of iodine in an alkali, iodide of nitrogen is obtained. The reaction is a general one in organic chemistry; both *amines and amides yield halogen substitution products in which the halogen atom is in combination with nitrogen, when treated with solutions of hypochlorites, hypobromites, or hypoiodites.*

When *N*-bromoacetamide is heated with an excess of alkali, a second reaction takes place as the result of which methylamine is formed:

$$CH_3CONHBr + 3NaOH = CH_3NH_2 + Na_2CO_3 + NaBr + H_2O$$

In the first step in the reaction the solution of bromine in sodium hydroxide can be replaced by one of bleaching powder, which is equally efficient, easier to handle, and less expensive. In both cases the replacement of hydrogen joined to nitrogen is brought

about as the result of the action of the salt of a halogen oxyac (HClO or HBrO).

Hofmann's reaction is a valuable method of preparing prima amines. As carbon is removed in the form of a carbonate fro an amide, it serves as a means of passing from one member of homologous series to the next which contains one carbon ato fewer. As acetamide is obtained from acetic acid, which formed as the result of the oxidation of ethyl alcohol, and methylamine, as will be shown later, is readily converted in methyl alcohol, it is possible through the application of this rea tion to pass from ethyl alcohol to methyl alcohol, or in gener from any alcohol to the one in the series with it which contains on carbon atom fewer. As the other classes of compounds may b prepared from alcohols, it is thus possible to "build down" in an homologous series. The steps in passing from ethyl alcohol t methyl alcohol are indicated by the following formulas:

$$C_2H_5OH \longrightarrow CH_3COOH \longrightarrow CH_3CONH_2 \longrightarrow CH_3CONHBr$$
$$\longrightarrow CH_3NH_2 \longrightarrow CH_3OH$$

Primary amines and their substitution products, suc as β-bromoethylamine, $CH_2BrCH_2NH_2$, can be prepared b Gabriel's synthesis (**575**).

210. The *reactions of methylamine* confirm in a striking man ner the structure which has been assigned to it. It resembl ammonia markedly in chemical properties.

With Hydrochloric Acid.—The gas fumes when brought int contact with hydrochloric acid as the result of the formation of salt, methylammonium chloride:

$$CH_3NH_2 + HCl = CH_3NH_3Cl$$

It forms with acids salts which crystallize well and unite wit metallic salts to form double salts which resemble those contai ing ammonium. The solution of the gas in water acts as a bas and can be titrated with acids. It precipitates the hydroxid of the heavy metals, some of which are soluble in excess of th solution of the amine.

The salts of methylamine, like those of amines in genera are decomposed by bases:

$$CH_3NH_3Cl + KOH = CH_3NH_2 + KCl + H_2O$$

With Nitrous Acid.—When methylamine is treated with nitrous acid, a reaction takes place which is analogous to that between ammonia and the acid. In the cold a nitrite is formed, but when gently heated decomposition takes place and nitrogen is set free. The reactions in the case of ammonia and methylamine are represented by the following equations:

$$NH_3 + HNO_2 = N_2 + H_2O + HOH$$

$$CH_3NH_2 + HNO_2 = N_2 + H_2O + CH_3OH$$

Two molecules of water are formed from the ammonium salt. In the case of the amine, as one hydrogen is replaced by a methyl radical, a molecule of methyl alcohol is produced. This reaction is one of importance as it is characteristic of substances which contain the NH_2 group. Nitrogen is not set free as the result of the action of nitrous acid on secondary or tertiary amines.

With Acyl Chlorides.—Methylamine, like ammonia, reacts readily with acyl chlorides. The equations for the reactions in the case of acetyl chloride are as follows:

$$CH_3CO.Cl + NH_3 = CH_3CO.NH_2 + HCl$$

$$CH_3CO.Cl + CH_3NH_2 = CH_3CO.NHCH_3 + HCl$$

Amides are conveniently prepared by the first reaction; the second yields substitution products of ammonia which contain one alkyl and one acyl radical.

Carbylamine Reaction.—When methylamine is warmed with chloroform and a solution of sodium hydroxide, it is converted into methyl isocyanide, CH_3NC (**250**), which possesses a very disagreeable odor. As other primary amines show a similar behavior the reaction is used as a test for substances of this class. It is known as the carbylamine reaction.

211. Dimethylamine, $(CH_3)_2NH$, is a representative of the class of secondary amines. It resembles closely methylamine in physical and chemical properties. It is a gas, with a strong fishy odor and can be condensed to a liquid which boils at 7.4°; it is found in herring brine. It is formed when methyl iodide is heated with ammonia. Methylamine is first formed and then converted into dimethylamine. The first reaction consists in the addition of the halide and ammonia:

$$CH_3I + NH_3 = CH_3NH_3I$$

The methylammonium iodide then probably interacts with ammonia according to the following equation:

$$CH_3NH_3I + NH_3 = NH_4I + CH_3NH_2$$

The methylamine produced unites with methyl iodide and forms dimethylammonium iodide:

$$CH_3NH_2 + CH_3I = (CH_3)_2NH_2I$$

From this salt dimethylamine is obtained by decomposition with an alkali:

$$(CH_3)_2NH_2I + KOH = (CH_3)_2NH + KI + H_2O$$

When methyl iodide and ammonia are heated together, the reaction does not stop with the formation of the salt of the secondary amine. The amine is liberated, and by the addition of another molecule of the iodide is converted into the salt of trimethylamine, $(CH_3)_3NHI$. Still another step in the reaction takes place. The tertiary amine is set free and a quaternary ammonium salt is formed as the result of the addition of methyl iodide:

$$(CH_3)_3N + CH_3I = (CH_3)_4N.I$$

With the formation of this salt, reaction ceases. The reaction between ammonia and an alkyl halide thus yields a mixture of the salts of the three classes of amines together with the salt of the quaternary ammonium base. The extent to which any one of the possible reactions predominates over the others is determined by the nature of the radical of the alkyl halide, and by the conditions under which the reaction takes place.

Preparation.—Dimethylamine is prepared conveniently in the laboratory from dimethylaniline (**517**). It is formed, along with trimethylamine, when the residue obtained in the production of sugar from beets is subjected to destructive distillation. This is the commercial source of these two amines.

Reactions.—The reaction which takes place between dimethylamine and *nitrous acid* is of importance, as it is an example of a general reaction used to distinguish secondary amines from the other classes of amines. Nitrous acid reacts with dimethylamine and forms a substance which belongs to the class known as nitroso compounds:

$$(CH_3)_2NH + HO.N:O = (CH_3)_2N.N:O + H_2O$$

The reaction brings about the replacement of the hydrogen in the NH group by the nitroso group (N=O). Nitrosodimethylamine is formed as a light yellow, insoluble liquid when sodium nitrite is added to an acidified aqueous solution of a salt of dimethylamine.

Acyl chlorides react with secondary amines:

$$(CH_3)_2NH + CH_3CO.Cl = CH_3CO.N(CH_3)_2 + HCl$$

The reaction takes place in most cases on simply mixing the reacting substances. No hydrochloric acid is evolved as that formed unites with a part of the amine and forms a salt:

$$(CH_3)_2NH + HCl = (CH_3)_2NH_2Cl$$

212. Trimethylamine, $(CH_3)_3N$, is a gas with a penetrating fishy odor, which may be condensed to a liquid that boils at 3.5°. It is prepared commercially from the residues of the beet-sugar industry, and from methyl chloride and ammonia. It can be prepared by heating an aqueous solution of ammonia or of ammonium chloride with formaldehyde under pressure at 120° to 160°:

$$2NH_3 + 9CH_2O = 2(CH_3)_3N + 3CO_2 + 3H_2O$$

Trimethylammonium chloride is formed when paraformaldehyde and ammonium chloride are heated together in an open vessel.

Trimethylamine, like other amines, forms salts with acids and unites with alkyl halides:

$$(CH_3)_3N + HCl = (CH_3)_3NHCl$$

$$(CH_3)_3N + CH_3I = (CH_3)_4NI$$

The amine is liberated from its salts when they are treated with a base:

$$(CH_3)_3NHCl + KOH = (CH_3)_3N + KCl + H_2O$$

213. Tetramethylammonium Hydroxide, $(CH_3)_4N.OH$.—This substance contains the largest number of methyl groups which can be held in combination with nitrogen. It is a colorless hygroscopic solid, which is very soluble in water and decomposes when strongly heated. It is prepared from the tetramethylammonium salt which is formed from trimethylamine and methyl iodide. The base cannot be prepared by heating the salts with

alkalies, as in the case of the preparation of the amines, since is not volatile without decomposition. It is formed when tet methylammonium iodide is shaken with silver oxide suspend in water:

$$(CH_3)_4NI + AgOH = (CH_3)_4N.OH + AgI$$

The double decomposition takes place in this case as the res of the insolubility of silver iodide. When tetramethylamm nium chloride is treated with potassium hydroxide, and alcol is used as the solvent, the base is formed as the result of the fa that potassium chloride is insoluble in alcohol:

$$(CH_3)_4NCl + KOH = (CH_3)_4N.OH + KCl$$

The salts of the amines and quaternary ammonium bas resemble inorganic salts in that they are ionized, and con quently take part in reactions of double decomposition.

214. Homologues of the Methylamines.—Many amines a quaternary ammonium bases are known. The effect of stru ture and content of carbon on the boiling points of amin is shown in the following table, which includes the lower membe of the series only:

Boiling Point of Amines, $C_nH_{2n+3}N$, °C. at 760 mm.

Alkyl radical	Primary	Secondary	Tertiary
Methyl	−6.5	7.4	3.5
Ethyl	16.6	56	89.5
n-Propyl	48.7	110.7	156
n-Butyl	76	161	214
n-Octyl	180	297	366

The amines with a small number of carbon atoms are inflam mable gases, which are very soluble in water, and possess characteristic ammoniacal fishy odor. The higher membe are odorless, and insoluble in water. The specific gravities the amines are less than one.

215. *Preparation of Amines.*—The amines may be prepared by t methods mentioned in the consideration of the methylamines. They s

formed by other reactions than those described. Primary amines result from the reduction of nitro compounds, cyanides, oximes, and hydrazones:

$$CH_3NO_2 + 6H = CH_3NH_2 + 2H_2O$$

$$CH_3CN + 4H = CH_3CH_2NH_2$$

$$(CH_3)_2C{:}NOH + 4H = (CH_3)_2CHNH_2 + H_2O$$

$$(CH_3)_2C{:}N.NH_2 + 4H = (CH_3)_2CHNH_2 + NH_3$$

Primary amines are also formed when the esters of isocyanic acid are distilled with an alkali, the reaction being analogous to the decomposition of isocyanic acid:

$$HNCO + 2KOH = K_2CO_3 + NH_3$$

$$C_2H_5NCO + 2KOH = K_2CO_3 + C_2H_5NH_2$$

The reaction is of interest as the first amine discovered was obtained in this way from ethyl isocyanate by Wurtz in 1848.

Amines which contain two or more different radicals can be prepared by the addition of alkyl halides to amines:

$$CH_3NH_2 + C_2H_5I = CH_3NH_2C_2H_5I$$

$$CH_3NH_2C_2H_5I + KOH = CH_3.C_2H_5.NH + KI + H_2O$$

216. Reactions of Amines.—The more important chemical properties of the amines have been illustrated in the consideration of the methylamines. They form salts with acids, such as nitric, sulphuric, and carbonic acids. The salts resemble inorganic salts in that they are ionized in solution. The presence of chlorine in dimethylammonium chloride can be shown, for example, by the tests used in inorganic qualitative analysis. The salts of hydrochloric, hydrobromic, and hydriodic acids are, in general, soluble in alcohol and by the use of this solvent the substituted ammonium chlorides may be separated from ammonium chloride. The double chlorides which contain the amines and platinum are difficultly soluble in alcohol and are of service in separating amines from other substances. The chloroplatinate which contains diethylammonium chloride has the formula $[(C_2H_5)_2NH_2]_2PtCl_6$. A number of substitution products of the amines are formed as the result of the decomposition of animal matter. The amines are frequently isolated by converting them into double salts, from which the former may be obtained by the action of a caustic alkali.

Sodium hypochlorite brings about the replacement by chlorin of the hydrogen joined to nitrogen. Thus, dipropylamine yield dipropylchloroamine, $(C_3H_7)_2NCl$, (*N*-chlorodipropylamine).

217. Identification of Amines.—When the qualitative analysi of a substance shows that it contains nitrogen the test for amine should be applied. If the substance is soluble in water an crystalline, it may be a salt of an amine. This may be deter mined by adding a solution of sodium hydroxide, when, if th compound is a salt, the amine will be set free. If an amine i liberated, the acid radical of the salt should be determined b the application of the ordinary tests for chlorides, sulphates, etc The amine may be identified by the determination of its physica properties and those of a salt. Salts of most amines with hydro chloric, hydrobromic, and hydriodic acid melt without decom position at temperatures that may be easily determined in th usual way. The determination of the melting points of the salt of amines which are gases at ordinary temperatures is the mos convenient way to effect their identification. If the substance i not a salt it may be a free amine. In this case it will dissolve i acids and a salt will be formed. Tripropylamine, for example, i an oil which is insoluble in water. It dissolves in dilute hydro chloric acid and is precipitated from the solution on the additio of an alkali. In the identification of certain amines it is ofte convenient to prepare and determine the melting point of thei acetyl derivatives.

218. Methods for Distinguishing Primary and Secondar Amines.—It is often advisable to determine to which class a amine belongs. There are many ways of doing this, but only few will be mentioned here.

Acetyl chloride reacts at ordinary temperatures with primar and secondary amines. Heat is evolved and in most cas solids are formed from liquid amines. Inactivity with th reagent indicates that the substance, previously shown t be an amine, is a tertiary amine. If an acetyl derivative formed, the carbylamine test (**210**) is applied. Some of th original substance is warmed with chloroform and an alcoholi solution of potassium hydroxide. The production of th characteristic, disagreeable odor is evidence that the substance a primary amine.

The three classes of amines may also be distinguished from one another by means of *nitrous acid*. An acidified solution of a salt of the amine is gently warmed with sodium nitrite. Nitrogen is evolved in the case of primary amines and an alcohol is formed. Insoluble nitroso compounds are formed from secondary amines. Most tertiary amines either do not react with nitrous acid or are oxidized by it. Care must be exercised in making this test. If a tertiary amine is present, the solution evolves oxides of nitrogen when heated, as the result of the decomposition of the nitrous acid produced from the sodium nitrite. The formation of a gas is not, therefore, proof that a primary amine is present. The gas evolved must be shown to be nitrogen, which can be separated from its oxides by passing the gases through a saturated solution of ferrous sulphate. The latter dissolves the oxides of nitrogen.

A convenient method of identifying the three classes of amines is that devised by Hinsberg (**482**).

Unsaturated Amines and Related Compounds

219. Vinylamine, $CH_2{=}CH.NH_2$, is an example of an amine which contains an unsaturated radical. It is made by an application of the general methods used in preparing unsaturated compounds. When β-bromoethylamine is heated with a solution of potassium hydroxide, hydrobromic acid is eliminated from the saturated compound:

$$BrCH_2CH_2.NH_2 + KOH = CH_2{:}CH.NH_2 + KBr + H_2O$$

The amine is soluble in water and boils at 55° to 56°. It unites readily with halogen acids, and forms substitution products of ethylamine. When treated with sulphurous acid, addition takes place at the double bond:

$$CH_2{:}CH.NH_2 + H_2SO_3 = CH_2(SO_3H)CH_2NH_2$$

The substance formed is *taurine*, which is found in the bile in combination with cholic acid.

220. Neurine, $(CH_3)_3N(CH{=}CH_2).OH$, is a quaternary ammonium base which contains one vinyl and three methyl radicals. It is formed during the putrefaction of meat. It is very poisonous, and belongs to the class of substances known as

ptomaines. This name has been given to the basic compounds formed during the decay of animal or vegetable matter, which is brought about by the action of bacteria. Many ptomaines are poisonous, and their occurrence in stale meat and fish has frequently caused death.

Neurine is a strong base and forms well-characterized salts. It can be synthesized by the method indicated by the following formulas:

$$(CH_3)_3N \xrightarrow{C_2H_4Br_2} (CH_3)_3N\begin{matrix}\diagup CH_2CH_2Br \\ \diagdown Br\end{matrix}$$

$$\xrightarrow{AgOH} (CH_3)_3N\begin{matrix}\diagup CH{=}CH_2 \\ \diagdown OH\end{matrix}$$

In the decomposition of animal and vegetable matter neurine is probably formed as the result of the elimination of water from choline.

221. Choline, $(CH_3)_3N\begin{matrix}\diagup CH_2CH_2OH \\ \diagdown OH\end{matrix}$, is a constituent of complicated compounds, called lecithins, which occur in bile, the brain, nerve tissue, the envelope of the red blood corpuscle, yolk of eggs, many seeds, and other animal and vegetable substances.

222. Lecithins are derived from glycerol by the replacement of the hydrogen atoms of the hydroxyl groups by certain acid radicals, one of which is the radical of phosphoric acid. When a lecithin is treated with barium hydroxide, partial saponification takes place. Choline and palmitic, stearic, or oleic acid are obtained, together with glycerophosphoric acid which has the constitution:

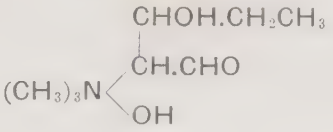
$$\begin{matrix}CH_2OH \\ | \\ CHOH \\ | \\ CH_2O{-}P\begin{matrix}\diagup O \\ \diagdown (OH)_2\end{matrix}\end{matrix}$$

The general formula of a lecithin is

$$\begin{matrix}CH_2OAc \\ | \\ CHOAc' \\ | \\ CH_2O{-}P\begin{matrix}\diagup O \\ \diagdown OH \\ \diagdown O{-}CH_2.CH_2.N(CH_3)_3.OH\end{matrix}\end{matrix}$$

Ac and Ac′ designate the acid radicals of palmitic, stearic, or oleic acids. The radicals in a lecithin may be the same or different. The choline present in the molecule is united to the phosphorus atom through oxygen joined to carbon. It is, therefore, present in the form of an ester. The hydroxyl group of choline which is joined to nitrogen is free. A lecithin has, consequently, basic properties and forms salts with acids. It also forms salts with bases as the result of the replacement of the hydrogen of the hydroxyl group joined to phosphorus.

223. Muscarine is a very poisonous substance which occurs in toadstools (*Amanita muscaria*) and certain other plants. It belongs to the class of compounds known as *alkaloids*, which are basic substances that occur in plants. The chemical properties of muscarine indicate that it is closely related in structure to choline. Its constitution is represented by the formula



Diamines

224. Ethylenediamine, $NH_2CH_2CH_2NH_2$, is the lowest member of the series of diamines. It is a liquid which boils at 117° and has a weak ammoniacal odor. It may be prepared from ethylene bromide and ammonia. The reactions of ethylenediamine are analogous to those of other primary amines. It differs from these, however, in that it forms a stable addition product with water which may be distilled without decomposition. The substance is, in all probability, a derivative of ammonium hydroxide with the structure

$$NH_2CH_2CH_2NH_3.OH.$$

Tetramethylenediamine, $NH_2(CH_2)_4NH_2$, usually called *putrescine*, is formed in the decay of animal matter. It melts at 27° and boils at 158°.

Cadaverine, $NH_2(CH_2)_5NH_2$, is a ptomaine, which is formed in the putrefaction of the human cadaver. It is a liquid, which boils at 178° to 179°, and is not poisonous. Its structure is indicated by its preparation from trimethylene cyanide:

$$NC.CH_2.CH_2.CH_2.CN + 8H = H_2N.CH_2.CH_2.CH_2.CH_2.CH_2.NH_2$$

Amides

225. The primary amides of the fatty acids, with the exception of formamide which is a liquid, are colorless, crystalline solids. The lower members of the series are very soluble in water and distill without decomposition at atmospheric pressure. As ordinarily prepared, they have a disagreeable odor, which in certain cases has been shown to be due to impurities. The boiling points of the amides increase in most cases with the increase in the number of carbon atoms, but the difference between the boiling points of adjacent members is not so great as in other homologous series. The relative effect on the boiling point of the replacement of the hydroxyl groups in alcohol and acids by the NH_2 group is very marked. While the boiling point of an amine is lower than that of the alcohol which contains the same alkyl radical, the boiling point of an amide is higher than that of the corresponding acid. Methyl alcohol boils at 64.5°, methylamine at −6.5°, acetic acid at 118.1°, and acetamide at 222°.

The general properties of amides can best be illustrated by a description of a typical member of the series.

226. Acetamide, $CH_3CO.NH_2$, is a colorless, crystalline solid which melts at 82° and boils at 222°. As ordinarily prepared it has an odor which is described as resembling that of the excrement of mice. When carefully purified it is odorless. It is readily soluble in water and in alcohol, and can be crystallized from benzene in which it dissolves to a less extent.

Preparation.—Acetamide may be most conveniently prepared by allowing a mixture of one volume of ethyl acetate and two volumes of concentrated ammonia to stand until a homogeneous solution is formed. The amide is obtained from the aqueous solution by distillation. The reaction which takes place is an example of a general reaction made use of in the preparation of other amides:

$$CH_3CO.OC_2H_5 + NH_3 = CH_3CO.NH_2 + C_2H_5OH$$

Acetamide is formed by the action of acetyl chloride on ammonia. The reaction is analogous to that by which an amine is formed:

$$CH_3CO.Cl + 2NH_3 = CH_3CO.NH_2 + NH_4Cl$$

$$CH_3Cl + 2NH_3 = CH_3NH_2 + NH_4Cl$$

The difference in the rate at which the reaction takes place in the two cases is marked. In the case of the acyl chloride, reaction takes place when the two substances are brought together at room temperature. It will be recalled, on the other hand, that in the preparation of amines by this reaction the alkyl halide is heated with ammonia at a high temperature to bring about the reaction. The introduction of an acyl radical into ammonia is thus much more readily accomplished than the introduction of an alkyl radical.

Amides are also formed by the action of acid anhydrides on ammonia:

$$\begin{matrix} CH_3CO \\ CH_3CO \end{matrix}\!\!>\!O + 2NH_3 = CH_3CONH_2 + CH_3COONH_4$$

The chlorides and anhydrides of acids yield in most cases the same substances with the various compounds with which they interact.

Acetamide and other members of this class can be prepared by heating the ammonium salts of the corresponding acids:

$$CH_3COONH_4 = CH_3CO.NH_2 + H_2O$$

The rate of the reaction is increased if some free acetic acid is present.

Chemical Reactions.—The most important reaction of amides is that which takes place when they are heated *with water*. Hydrolysis results, and the bond between carbon and nitrogen is broken. Acetamide, for example, is converted into ammonium acetate as the result of the formation of acetic acid and ammonia:

$$CH_3CO.NH_2 + H.OH = CH_3CO.OH + NH_3$$

The rate of the reaction is markedly increased in the presence of acids or bases. As in the case of the hydrolysis of esters, the hydrogen and hydroxyl ions act as catalytic agents, the hydroxyl ion effecting the hydrolysis more rapidly.

It is interesting to note that amines do not undergo a similar hydrolysis; methylamine, for example, is not converted by alkalies into methyl alcohol and ammonia.

It is difficult to break the bond which links carbon and nitrogen when the carbon atom is in an alkyl radical. When the radical is an acyl one, however, the nitrogen may be removed by hydrolysis in most cases as ammonia.

When an amide is heated *with a dehydrating agent* water is eliminated and a cyanide is formed. Methyl cyanide can be prepared by distilling acetamide with phosphorus pentoxide:

$$CH_3CONH_2 = CH_3CN + H_2O$$

Under proper conditions a cyanide may be converted into an amide.

Like primary amines, the primary amides react *with nitrous acid;* in both cases the NH_2 group is replaced by OH:

$$CH_3CONH_2 + HNO_2 = CH_3COOH + N_2 + H_2O$$
$$CH_3NH_2 + HNO_2 = CH_3OH + N_2 + H_2O$$

The reactions of the amides *with hypobromites* are analogous to those of the primary and secondary amines with this reagent; one or two atoms of hydrogen are replaced by bromine:

$$CH_3CONH_2 + Br_2 + KOH = CH_3CONHBr + KBr + H_2O$$
$$CH_3CONH_2 + 2Br_2 + 2KOH = CH_3CONBr_2 + 2KBr + 2H_2O$$

It will be remembered that the monobromoamides are formed in the preparation of amines by Hofmann's reaction.

Amides of Dibasic Acids

227. Urea, $CO(NH_2)_2$, is the amide of carbonic acid. It is sometimes called carbamide. It was first isolated from urine (whence its name) in which it occurs in relatively large quantities, as it is the chief waste nitrogenous substance formed as the result of the metabolism of foods. An adult excretes from 20 to 30 grams of urea per day. Urea may be isolated from urine by evaporating the latter and adding concentrated nitric acid. The nitrate of urea, which precipitates, is recrystallized from moderately concentrated nitric acid to remove colored substances present. It is then dissolved in water and barium carbonate is added. The salt is decomposed, and barium nitrate, carbon dioxide, and urea are formed. The solution is finally evaporated to dryness and the urea extracted with hot alcohol.

Urea crystallizes from water, in which it is readily soluble, in long prisms which melt at 132.7°.

Preparation.—Urea can be prepared in a number of ways which furnish evidence of its structure. It is formed by the action of ammonia on carbonyl chloride:

$$COCl_2 + 2NH_3 = CO(NH_2)_2 + 2HCl$$

and on ethyl carbonate:

$$CO(OC_2H_5)_2 + 2NH_3 = CO(NH_2)_2 + 2C_2H_5OH$$

Ammonium carbonate yields urea when heated in a sealed tube at 130° to 140°:

$$CO(ONH_4)_2 = CO(NH_2)_2 + 2H_2O$$

It should be noted that in these ways of preparing urea, use has been made of reactions which are of general application in the preparation of amides.

Urea is manufactured by heating ammonium carbamate under pressure:

$$NH_2COONH_4 = CO(NH_2)_2 + H_2O$$

It is formed when an aqueous solution of ammonium sulphate and potassium cyanate is evaporated. Ammonium cyanate is first formed, and then passes by intramolecular rearrangement into urea:

$$N{\equiv}C{-}O{-}NH_4 \rightleftharpoons O{=}C\begin{matrix}NH_2\\NH_2\end{matrix}$$

This reaction is of particular interest as urea was first obtained in this way by Wöhler in 1828. The discovery of this synthesis of urea had a marked effect on the development of organic chemistry. It was the first example of the formation in the laboratory from so-called inorganic compounds, of an organic compound produced in the body as the result of the vital force. The reaction by which urea is formed from ammonium cyanate has been shown to be a reversible one. Silver cyanate is precipitated when silver nitrate is added to a solution of urea in boiling water. The reaction has been investigated quantitatively in the study of the law of mass action.

Reactions.—Urea takes part in reactions which are characteristic of amides. When heated *with an alkali* it is hydrolyzed:

$$CO(NH_2)_2 + H_2O = CO_2 + 2NH_3$$

The same decomposition is effected by an organism known as *Micrococcus ureae*, which causes the liberation of ammonia from urine which is allowed to stand for some time.

When urea is treated with *sodium hypochlorite* or sodium hypobromite, stable substitution products are not formed as in the case of acetamide, but complete decomposition results. The reaction, which takes place in the main according to the equation

$$CO(NH_2)_2 + 3NaOBr = N_2 + 3NaBr + CO_2 + 2H_2O$$

is made use of in the determination of the urea content of urine. The volume of the nitrogen formed is a measure of the amount of urea present. The reaction between urea and nitrous acid is normal, and carbonic acid and nitrogen are formed.

Urea resembles the amines in certain of its reactions. It forms salts with strong acids. The nitrate $CO(NH_2)_2.HNO_3$ and oxalate $2CO(NH_2)_2.(COOH)_2$ crystallize well. Urea, like methylamine, reacts with acetyl chloride, and acetylurea is formed, $CH_3CO.NH.CO.NH_2$. A number of such compounds, which are called *ureides*, are known.

When urea is heated with formaldehyde a colorless glass-like substance is formed which transmits ultra-violet light. The product will, no doubt, find useful applications.

228. *Biuret.*—When urea is heated it loses ammonia, and biuret is among the products formed:

$$\begin{matrix} OC\langle^{NH_2}_{NH_2} \\ OC\langle^{NH_2}_{NH_2} \end{matrix} = \begin{matrix} OC\langle^{NH_2}_{NH} \\ OC\langle^{\ }_{NH_2} \end{matrix} + NH_3$$

Biuret is a crystalline substance which melts at 193°. When it is treated with a solution of potassium hydroxide or sodium hydroxide which contains a trace of copper sulphate, a characteristic reddish-violet color appears. This is called the *biuret reaction*. The reaction is given by proteins, and is a useful test for these substances. Other substances which contain two $CONH_2$ groups linked together by a nitrogen or carbon atom, or by one or more CONH groups, give this test.

229. Guanidine is related to urea; its structure is represented by the formula $HN{=}C(NH_2)_2$. The replacement of the oxygen atom in urea by the NH group has a marked effect on the properties of the resulting substance. Guanidine possesses strong basic properties; it is a colorless, crystalline substance, which absorbs moisture and carbon dioxide from the air. It is usually prepared by heating ammonium thiocyanate at 180° to

185°. It is formed when cyanamide is heated with ammonium chloride:

$$N{\equiv}C{-}NH_2 + NH_3.HCl = H_2N{-}\underset{\underset{NH}{\|}}{C}{-}NH_2.HCl$$

230. Carbamic acid, $OC\begin{cases}NH_2\\OH\end{cases}$, which may be considered as derived from carbonic acid by the replacement of one hydroxyl group by the amido group, is not known in the free condition. The ammonium salt of this acid is formed when carbon dioxide and ammonia are brought together:

$$CO_2 + 2NH_3 = OC\begin{cases}NH_2\\ONH_4\end{cases}$$

Ammonium carbamate is a constituent of commercial ammonium carbonate. The salts of carbamic acid are hydrolyzed by boiling with water, the reaction being analogous to that with other amides:

$$OC\begin{cases}NH_2\\OK\end{cases} + H_2O = OC\begin{cases}OH\\OK\end{cases} + NH_3$$

231. Oxamide, $(CONH_2)_2$, is most readily prepared by shaking methyl or ethyl oxalate with concentrated ammonia:

$$(COOC_2H_5)_2 + 2NH_3 = (CONH_2)_2 + 2C_2H_5OH$$

It is formed in the partial hydrolysis of cyanogen:

$$\begin{matrix}CN\\|\\CN\end{matrix} + 2H_2O = \begin{matrix}CONH_2\\|\\CONH_2\end{matrix}$$

and when ammonium oxalate is heated:

$$\begin{matrix}COONH_4\\|\\COONH_4\end{matrix} = \begin{matrix}CONH_2\\|\\CONH_2\end{matrix} + 2H_2O$$

It is a colorless crystalline powder which is insoluble in water. At about 180° it sublimes, without melting, with partial decomposition into cyanogen and water. When heated with water in the presence of acids or alkalies it is hydrolyzed, and oxalic acid and ammonia are formed.

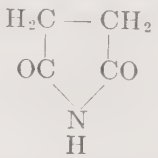
When the acid ammonium salt of oxalic acid is heated, water is lost, as in the case of the neutral salt, and a compound called *oxamic acid* is obtained:

$$\begin{matrix}COONH_4\\ |\\ COOH\end{matrix} = \begin{matrix}CONH_2\\ |\\ COOH\end{matrix} + H_2O$$

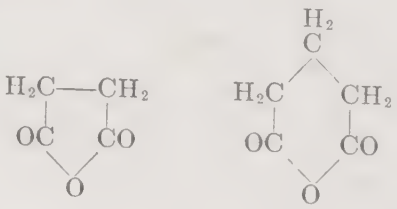
Analogous compounds may be obtained from other dibasic acids: thus, succinamic acid, $\begin{matrix}CH_2CONH_2\\ |\\ CH_2COOH\end{matrix}$, may be prepared from succinic acid, $(CH_2COOH)_2$. Substitution products of succinamic acid and similar compounds are important constituents of certain plants. Some of these will be described later.

232. Succinamide, $(CH_2CONH_2)_2$, is prepared from ethyl succinate and ammonia. It is a crystalline substance, which melts at 243°, and is sparingly soluble in water. The reactions of succinamide are, in general, analogous to those of oxamide. When heated to a high temperature, however, it is not converted into the corresponding nitrile and water, but by the loss of one molecule of ammonia passes into *succinimide,* $(CH_2CO)_2NH$.

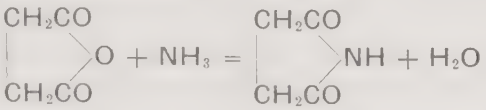
233. The formation of *imides* takes place in the case of dibasic acids which contain a straight chain of four or five carbon atoms. In the resulting compounds the atoms are arranged in what is called a "ring." The graphic formula of succinimide may be written in a way which makes this clear:

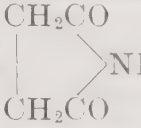


The tendency for atoms to arrange themselves in rings which contain five or six atoms is marked, and many compounds of the greatest importance possess this kind of structure. It will be recalled that dibasic acids which contain four or five carbon atoms readily pass into anhydrides with the formation of ring compounds containing five or six atoms in the ring. The anhydrides of succinic and glutaric acids have the structure represented by the following formulas:



234. Succinimide is formed when succinic anhydride is heated in a stream of dry ammonia:



It is readily soluble in water, from which it crystallizes with one molecule of water. The anhydrous imide melts at 124° and boils at 288°. Although succinimide has a neutral reaction and does not decompose carbonates, it forms salts in which one hydrogen is replaced by a metallic atom. Potassium hydroxide and succinimide react in alcoholic solution to form a salt to which the formula  is assigned.

235. Identification of Amides.—The reaction of primary amides which is of the most importance in their identification, is that which takes place when they are heated with alkalies. If a substance has been found to contain nitrogen, it should first be tested to determine whether it is an amine, a salt of an amine, or an ammonium salt. Amines or ammonia will be set free from their salts when they are treated with a *cold* solution of sodium hydroxide. If no reaction takes place, the substance should be heated with a boiling solution of the alkali. Under these conditions an amide is decomposed and ammonia is liberated, which is recognized by its odor. Substituted amides like *N*-methylacetamide, $CH_3CO.NHCH_3$, yield substituted ammonias.

Nitriles also yield ammonia when boiled with a solution of an alkali. The test is, therefore, not conclusive. The physical properties of the two classes of compounds are different, and are thus helpful in their identification. The amides of the fatty acids are solids which boil at comparatively high temperatures. They are also, in most cases, heavier than water. The nitriles of these acids, on the other hand, except those of a very high molecular weight, are liquids of comparatively low boiling point. The nitriles are lighter than water.

To complete the identification, the melting point or boiling point of the amide is determined. It is often helpful to determine both of these constants as an aid in the identification of

amides and other substances. The conclusion arrived at should be verified by converting the amide into another compound, and determining its physical properties. The amides of monocarboxylic acids may be conveniently converted into nitriles, and those of the dicarboxylic acids into the corresponding acids.

Problems

1. Summarize in the form of equations the methods of preparing amines and amides. Indicate the general methods that can be used for both classes of compounds and those that apply to one class only.

2. Summarize, in the form of equations, the reactions of amines and amides. State in which reactions the amines resemble amides in behavior and in which they do not.

3. Write equations for reactions used in distinguishing primary, secondary, and tertiary amines.

4. Write equations for reactions by which the substances having the following formulas may be prepared:

(*a*) $(C_2H_5)_2C_3H_7N$ from C_2H_5OH and C_3H_7OH; (*b*) $C_4H_9NH_2$ from C_4H_9COOH, (*c*) $(C_2H_5)_3C_3H_7NOH$, (*d*) $C_3H_7CON(CH_3)_2$, (*e*) $(CH_3)_2CH\text{-}CONHC_3H_7$.

5. How could you distinguish by chemical tests the following: (*a*) $(CH_3)_4NCl$ and $(C_3H_7)_2NCl$; (*b*) $CH_3CONHC_2H_5$ and $CH_3CON(C_2H_5)_2$; (*c*) $CH_3CON(C_2H_5)_2$ and $CH_3CH_2N(C_2H_5)_2$; (*d*) $C_5H_{11}NH_3Cl$ and $ClC_5H_{10}NH_2$; (*e*) CH_3CONBr_2 and $BrCH_2CONH_2$; (*f*) oxamide and ammonium oxalate; (*g*) succinimide and succinamide; (*h*) urea and ammonium acetate?

6. Write equations for reactions by which choline could be prepared from methyl alcohol and ethyl alcohol.

CHAPTER XII

CYANOGEN AND RELATED COMPOUNDS

236. Many organic compounds contain carbon united with nitrogen in such a way that in their chemical transformations these elements remain in combination, and thus pass from one compound to another. When organic substances were first investigated this phenomenon was observed, and the name radical (from *radix*, root) was given to this group of atoms (CN) and to others which likewise passed unchanged from one compound to another.

It was shown that the composition and properties of many compounds containing the cyanogen radical were similar to those of the corresponding compounds which contained a halogen atom. The analogy between the two series of compounds is shown by the following formulas:

$(CN)_2$	HCN	KCN	$Hg(CN)_2$	HCNO	CH_3CN
Cl_2	HCl	KCl	$HgCl_2$	HClO	CH_3Cl

This relation indicated that a group of elements could play the part of an atom. The first attempt made to solve the mystery of complex organic compounds was directed toward the discovery of the radicals which they contained. This was the beginning of the structure theory of organic chemistry.

The cyanogen radical which may be introduced into many compounds is present in potassium cyanide, from which such compounds are prepared. Only the more important substances which contain this radical will be described here.

237. Cyanogen, $(CN)_2$, is formed in small quantity when nitrogen is passed over an electric arc formed between carbon poles, and when ammonium oxalate is heated:

$$(COONH_4)_2 = (CN)_2 + 4H_2O$$

It may be prepared by heating the cyanide of silver or of mercury:

$$Hg(CN)_2 = Hg + (CN)_2$$

There is formed at the same time a brown amorphous substance, called *paracyanogen*, to which the formula $(CN)_x$ is assigned. It is a polymer of cyanogen of unknown molecular weight, which is converted into cyanogen by heating at a high temperature.

Cyanogen is more conveniently prepared by warming an aqueous solution of copper sulphate and potassium cyanide:

$$CuSO_4 + 2KCN = K_2SO_4 + Cu(CN)_2$$

$$2Cu(CN)_2 = 2CuCN + (CN)_2$$

These reactions are analogous to those which take place between copper sulphate and potassium iodide in aqueous solution. It will be recalled that cuprous iodide and iodine are formed.

Cyanogen is a colorless gas, which can be condensed to a liquid boiling at $-20.5°$. It possesses a peculiar, pungent odor and is excessively poisonous. It burns with a blue flame surrounded by a rose-pink mantle. Cyanogen is moderately soluble in water; the aqueous solution is unstable, and, on standing, deposits a brown amorphous substance of unknown structure, called azulmic acid; the solution then contains ammonium oxalate and other substances. The formation of cyanogen from ammonium oxalate and the change in the reverse direction indicate that cyanogen is the nitrile (**247**) of oxalic acid:

$$\begin{matrix} C & N \\ | & \\ C & N \end{matrix} + 4H_2O \rightleftharpoons \begin{matrix} COONH_4 \\ | \\ COONH_4 \end{matrix}$$

Cyanogen is absorbed by a solution of potassium hydroxide, the reaction which takes place being analogous to that between the alkali and a halogen:

$$2KOH + Cl_2 = KCl + KClO + H_2O$$

$$2KOH + (CN)_2 = KCN + KCNO + H_2O$$

238. Cyanogen chloride, CN.Cl, is formed by the action of chlorine on an aqueous solution of hydrocyanic acid:

$$H—C\equiv N + Cl_2 = Cl—C\equiv N + HCl$$

Cyanogen chloride is a colorless, very poisonous liquid which boils at 13.8°. It was used to a limited degree as a war gas. It has largely replaced hydrocyanic acid in fumigating ships; the presence of any residual gas, after fumigation has been accom-

plished, can be detected because cyanogen chloride produces a copious flow of tears.

Cyanogen chloride polymerizes readily to cyanuric chloride, $C_3N_3Cl_3$, a solid which melts at 146°. Cyanogen chloride and ammonia interact and form cyanamide:

$$CN.Cl + 2NH_3 = CN.NH_2 + NH_4Cl$$

239. Cyanamide, $CN.NH_2$, is a crystalline, hygroscopic solid which polymerizes readily. Like other compounds in which the amido group is in combination with a negative radical, metallic derivatives may be formed by the replacement of the hydrogen atoms. Silver cyanamide, $CN.NAg_2$, is a yellow, amorphous substance which, unlike most silver salts, is insoluble in ammonia.

When lime and carbon are heated to a red heat in an atmosphere of nitrogen, calcium cyanamide is formed as the result of the action of nitrogen on the calcium carbide first produced:

$$CaC_2 + N_2 = CN.NCa + C$$

Calcium cyanamide is decomposed slowly by water, and ammonia is formed:

$$CN.NCa + 3H_2O = 2NH_3 + CaCO_3$$

This and other reactions of cyanamide and its derivatives indicate that the compound is the amide of cyanic acid, $N \equiv C—OH$. The decomposition of calcium cyanamide can be explained on this assumption. Hydrolysis first yields cyanamide which like other amides is converted by water into an acid and ammonia:

$$CN.NCa + 2H_2O = CN.NH_2 + Ca(OH)_2$$

$$CN.NH_2 + H_2O = CN.OH + NH_3$$

Cyanic acid reacts rapidly with water and forms ammonia and carbon dioxide, which in this case would convert the calcium hydroxide formed into a carbonate:

$$CNOH + H_2O = NH_3 + CO_2$$

Calcium cyanamide is made on a commercial scale and is being used as a fertilizer. The substance is of special interest as by means of it atmospheric nitrogen may be changed into a form (ammonia) in which it serves as a plant food.

When barium carbide is heated in nitrogen, barium cyanide is formed:

$$BaC_2 + N_2 = Ba(CN)_2$$

The reaction furnishes a means of preparing cyanides from atmospheric nitrogen.

240. Hydrocyanic acid, HCN, commonly called prussic acid, occurs in the free condition in certain plants. It is produced as the result of the decomposition of a substance called amygdalin (**372**) which occurs in the leaves of the cherry and laurel, in bitter almonds, peach kernels, and other substances. It can be formed by exposing a mixture of hydrogen and nitrogen to an electric arc between carbon poles; under these conditions about 4.7 per cent of the gases is converted into hydrocyanic acid.

Hydrocyanic acid is a colorless liquid which boils at 26°, and when cooled forms crystals which melt at −14°. It has an odor which is similar to that of the oil of bitter almonds. It burns with a pale blue flame. Hydrocyanic acid is one of the most powerful poisons: 0.05 gram is said to be a fatal dose. Hydrogen peroxide or the inhalation of air containing chlorine are said to be antidotes for hydrocyanic acid. The poisonous property of the acid is in some way associated with the CN ion. Substances from which this ion is produced are poisonous, whereas those, like potassium ferrocyanide, which do not give a simple CN ion are not poisonous. Hydrocyanic acid is used to destroy pests on fruit trees.

The acid is prepared by distilling potassium cyanide or potassium ferrocyanide with a dilute solution of sulphuric acid:

$$KCN + H_2SO_4 = KHSO_4 + HCN$$

The anhydrous acid is obtained from the solution prepared in this way by fractional distillation.

Hydrocyanic acid is readily soluble in water; the solution is unstable and deposits on standing a brown amorphous substance. Ammonium formate is among the products of the decomposition. Hydrocyanic acid thus appears to be the nitrile of formic acid:

$$H—C{\equiv}N + 2H_2O = H.COONH_4$$

This reaction will take place in the direction opposite to that written, as hydrocyanic acid is formed when ammonium formate is heated.

Hydrocyanic acid is a very weak acid; it scarcely reddens blue litmus. It reacts with hydroxides but not with carbonates. The cyanides are decomposed by carbonic acid. The soluble salts—those of the alkali metals, the alkaline-earth metals, and mercuric cyanide—may be made by the interaction of the acid and bases, the insoluble ones by double decomposition.

241. The *structure of hydrocyanic acid* is deduced from its reactions. On reduction it yields methylamine:

$$H—C\equiv N + 4H = CH_3NH_2$$

and, on hydrolysis, formic acid and ammonia:

$$H—C\equiv N + 2H_2O = H—\overset{\overset{O}{\|}}{C}—OH + NH_3$$

These reactions can be interpreted best on the assumption that in the acid the hydrogen atom is joined to carbon. Hydrocyanic acid appears to bear the same relation to formic acid that methyl cyanide, CH_3CN, bears to acetic acid, $CH_3.COOH$, and it is shown below that methyl cyanide has the structure represented by the formula $H_3C—C\equiv N$ in which the methyl group is in combination with carbon.

242. Potassium cyanide, KCN, is formed when potassium burns in cyanogen, and when nitrogen is passed into a mixture of carbon and fused potassium carbonate. It is prepared by strongly heating potassium ferrocyanide:

$$K_4Fe(CN)_6 = 4KCN + FeC_2 + N_2$$

As one-third of the nitrogen is lost in the reaction, the ferrocyanide is frequently fused with sodium:

$$K_4Fe(CN)_6 + 2Na = 4KCN + 2NaCN + Fe$$

The mixture of cyanides finds applications in the industries. It is used in the extraction of silver and gold from their ores.

Potassium cyanide crystallizes in colorless plates, is readily soluble in water, and very slightly soluble in alcohol. It is an active poison. The aqueous solution is unstable; among the products formed on standing are potassium formate and ammo-

nia. Fused potassium cyanide is a powerful reducing agent it is used to effect the reduction of metallic oxides:

$$PbO + KCN = Pb + KCNO$$

The insoluble cyanides dissolve in solutions of potassium cyanide, and double salts are formed. These belong to two classes: those which are readily decomposed by dilute acids in the cold and yield hydrocyanic acid, and those which yield complex acids. When, for example, the double salt of the formula $KAg(CN)_2$ is treated with an acid, silver cyanide is precipitated and hydrocyanic acid is formed as the result of the action of the acid on potassium cyanide. When, however, potassium ferrocyanide, $K_4Fe(CN)_6$, is treated with an acid, a simple double decomposition takes place and hydroferrocyanic acid is formed

$$K_4Fe(CN)_6 + 4HCl = 4KCl + H_4Fe(CN)_6$$

The double cyanides of gold, nickel, and silver are used in electroplating. When the complex salt of the composition $KAg(CN)_2$ is dissolved in water, decomposition into its constituents does not take place, but the salt ionizes according to the equation

$$KAg(CN)_2 \rightleftharpoons \overset{+}{K} + Ag(\overset{-}{CN})_2$$

It has been found that silver or gold produced as the result of the decomposition of the complex ions is deposited more evenly than that deposited from the simple salts. The complex salts are, accordingly, used in plating.

The soluble salts of hydrocyanic acid are hydrolyzed in aqueous solution, and consequently show an alkaline reaction:

$$KCN + HOH \rightleftharpoons KOH + HCN$$

When the solution is boiled the hydrocyanic acid is hydrolyzed further, and formic acid and ammonia are formed (**241**).

243. Sodium cyanide, NaCN, can be prepared by two methods in which the source of nitrogen is the air, and which for this reason are of particular interest. In the *Bucher process* a mixture of sodium carbonate and carbon is heated at 800° to 1000° with nitrogen in the presence of iron, which serves as a catalytic agent:

$$Na_2CO_3 + 4C + N_2 = 2NaCN + 3CO$$

Calcium cyanamide is converted into sodium cyanide when it is fused with sodium chloride and carbon at about 750°:

$$CaCN_2 + C + 2NaCl = 2NaCN + CaCl_2$$

Sodium cyanide is used in the extraction of gold from its ores, for the preparation of hydrocyanic acid, and for other purposes.

244. Potassium ferrocyanide, $K_4Fe(CN)_6.3H_2O$, yellow prussiate of potash, may be formed by dissolving ferrous hydroxide in potassium cyanide:

$$Fe(OH)_2 + 2KCN = 2KOH + Fe(CN)_2$$
$$Fe(CN)_2 + 4KCN = K_4Fe(CN)_6$$

It is manufactured by heating to a high temperature a mixture of potassium carbonate, scrap iron, and refuse animal material, such as horn shavings, hair, leather scraps, and blood. After cooling, the fused mass is extracted with water, filtered, and the solution evaporated to crystallization. Potassium ferrocyanide is also prepared on a commercial scale from the spent iron oxide from the purification of illuminating gas. It is used for making potassium cyanide, Prussian blue, and potassium ferricyanide; in calico printing and in dyeing; and as a reagent. When distilled with dilute sulphuric acid it is decomposed and hydrocyanic acid is formed; at a higher temperature, with a stronger acid (about 90 per cent H_2SO_4), carbon monoxide is produced. The decomposition serves as a convenient way to prepare this gas. The reaction consists in the hydrolysis of hydrocyanic acid to formic acid and the dehydration of the latter:

$$K_4Fe(CN)_6 + 3H_2SO_4 = 2K_2SO_4 + FeSO_4 + 6HCN$$
$$HCN + 2H_2O = HCOOH + NH_3$$
$$HCOOH + H_2SO_4 = CO + H_2SO_4.H_2O$$

When potassium ferrocyanide is added to a solution of a ferric salt, a characteristic blue precipitate, called Prussian blue, is formed:

$$3K_4Fe(CN)_6 + 4FeCl_3 = Fe_4[Fe(CN)_6]_3 + 12KCl$$

The reaction is one of double decomposition by which insoluble ferric ferrocyanide is formed.

245. Potassium ferricyanide, $K_3Fe(CN)_6$, red prussiate of potash, crystallizes in anhydrous blood-red prisms. It is pre-

pared by the action of an oxidizing agent on potassium ferrocyanide. Chlorine is usually used. The gas is passed into the solution of the ferrocyanide until oxidation is complete. This is shown by testing the solution with ferric chloride, when, if any ferrocyanide is present, Prussian blue will be formed. Ferric chloride and potassium ferricyanide produce a brown color. The equation for the oxidation is:

$$2K_4Fe(CN)_6 + Cl_2 = 2KCl + 2K_3Fe(CN)_6$$

246. An alkaline solution of potassium ferricyanide is an oxidizing agent and is used in calico printing. The salt is also used in making *blue-print paper*, which is prepared by coating paper with a solution of potassium ferricyanide and a ferric salt which is rapidly reduced by sunlight. Ferric ammonium citrate is generally used for this purpose, as the salt of an organic acid is more sensitive to light than one of an inorganic acid. This increased sensitiveness is due to the fact that the acid radical present readily undergoes oxidation and thus assists in the reduction of the iron. When paper so prepared is exposed to light, the ferric citrate is reduced to a ferrous salt. On treatment with water, the ferrous compound formed on the parts of the paper which were exposed to the action of light, interacts with the potassium ferricyanide and Turnbull's blue is formed. No reaction takes place where the paper has not been exposed, and, on washing, the soluble salts are removed and the original color of the paper appears.

Alkyl Cyanides

247. When potassium cyanide is heated with an alkyl halide, a reaction takes place that is analogous to many with which the student is familiar. The metal and the halogen unite to form a salt, and the radicals to form an organic compound:

$$KCN + RI = KI + RCN$$

The substances prepared in this way are called cyanides or *nitriles*. The name of a particular member of this class is determined by the radical in combination with the CN group. Thus, CH_3CN is methyl cyanide or acetonitrile, and C_2H_5CN is ethyl cyanide or propionitrile. The prefix added to nitrile is derived from the name of the acid into which the nitrile passes on hydrolysis.

The nitriles of lower molecular weight are colorless liquids which boil at atmospheric pressure without decomposition. They are soluble in water, but the solubility decreases with

increasing molecular weight; octyl cyanide, $C_8H_{17}CN$, is almost insoluble in water. The nitriles which contain 16 or more carbon atoms are crystalline solids. They all are lighter than water, the specific gravity varying between 0.78 and 0.90.

248. Methyl cyanide, CH_3CN, may be considered as a representative of the class. It is a liquid of strong but not unpleasant odor, which boils at 82°. It is formed by boiling a solution of methyl iodide and potassium cyanide in alcohol diluted with water. The reaction takes place slowly. It is best prepared by distilling ammonium acetate or acetamide with phosphorus pentoxide:

$$CH_3CONH_2 + P_2O_5 = CH_3CN + 2HPO_3$$

Nitriles, in general, may be prepared by analogous reactions, and by distilling a dry mixture of potassium cyanide and a salt of an alkylsulphuric acid:

$$KCN + C_2H_5SO_4K = K_2SO_4 + C_2H_5CN$$

When boiled with a solution of an acid or an alkali the nitriles are hydrolyzed and acids and ammonia are formed:

$$CH_3CN + 2H_2O = CH_3COOH + NH_3$$

When they are heated to a high temperature with water alone, however, they interact with a smaller proportion of water and an amide is formed:

$$CH_3C{\equiv}N + H_2O = CH_3.CONH_2$$

The addition of water is made possible by the unsaturated nature of the linking between the carbon and nitrogen atoms in the CN radical.

It should be noted that in the hydrolysis of the cyanides the reaction which takes place is not of the same nature as the hydrolysis of esters; methyl cyanide, for example, does not yield methyl alcohol and hydrocyanic acid.

Nitriles are reduced by nascent hydrogen to primary amines; methyl cyanide yields ethylamine:

$$CH_3C{\equiv}N + 4H = CH_3CH_2NH_2$$

This reaction indicates that in methyl cyanide the alkyl radical is joined to carbon, for if it had the structure represented by

the formula $CH_3—N—C$, in which the carbon atoms are joined through nitrogen, we should expect to get, on reduction, dimethyl amine, in which the carbon atoms are so joined:

$$CH_3—N—C + 4H = CH_3—\underset{\displaystyle H}{\overset{|}{N}}—CH_3$$

The fact that the hydrolysis of nitriles leads to the formation of ammonia and acids which contain the same number of carbon atoms as the nitrile, is strong evidence in favor of the view that in these compounds the nitrogen atom is at the end of the chain.

Alkyl Isocyanides

249. When an alkyl halide is treated with silver cyanide reaction takes place in the usual way; a silver halide and an organic compound are formed. The product, however, is not an alkyl cyanide, as is the case when potassium cyanide is used, but an isomeric compound. The substances prepared from silver cyanide are called isocyanides, isonitriles, or carbylamines. The last name was given to them on account of the fact that they unite with acids and thus resemble the amines. The addition products do not, however, resemble salts in their chemical properties. When hydrogen chloride is passed into an ethereal solution of methyl isocyanide, a compound of the formula $2CH_3NC.3HCl$ is formed which is decomposed when brought into contact with water.

The isocyanides are colorless poisonous liquids, which are sparingly soluble in water, and possess a disagreeable, almost unbearable odor. They are lighter than water. The boiling point of a cyanide is higher than that of the isocyanide which contains the same number of carbon atoms; thus, ethyl cyanide boils at 97.1° and ethyl isocyanide at 79°. The difference in the physical and chemical properties of cyanides and isocyanides is attributed to a difference in structure. It has been shown that the reactions of the cyanides lead to the view that in them the alkyl radical are in combination with carbon, R—CN. On the other hand, the reactions of isocyanides can best be explained on the assumption that the radical is joined to nitrogen, R—NC. A study of the chemical properties of methyl isocyanide will make clear the reasons for this statement.

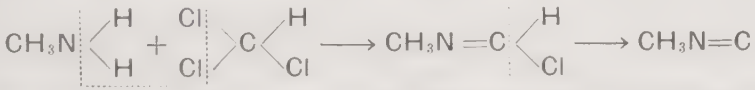
250. Methyl isocyanide, CH_3NC, is formed by heating methyl iodide with silver cyanide:

$$CH_3I + AgNC = CH_3NC + AgI$$

As some methyl cyanide is formed in the reaction, the substance is best prepared by heating methylamine with an alcoholic solution of chloroform and potassium hydroxide (carbylamine reaction, Sec. **210**):

$$CH_3NH_2 + CHCl_3 + 3KOH = CH_3NC + 3KCl + 3H_2O$$

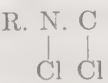
This reaction, which serves as a general method of preparing isocyanides, throws some light on their structure. In the primary amines the alkyl group is in combination with nitrogen, and it seems probable that in their change to isocyanides this union remains intact. The reaction is best explained on the view that is represented by the following formulas:



Methyl isocyanide is stable toward alkalies but it is hydrolyzed at ordinary temperatures in the presence of acids, and methylamine and formic acid are produced:

$$CH_3—N=C + 2H_2O = CH_3NH_2 + HCOOH$$

251. Bivalent Carbon.—The formation of isocyanides by the carbylamine reaction indicates that in these compounds the alkyl group is joined to nitrogen. Should the graphic symbol be written $CH_3—N=C$ or $CH_3N\equiv C$? According to the first formula carbon is represented as having the valence 2. It was assumed for a long time that in all organic compounds carbon showed a constant valence of 4, but the result of the study of the reactions of isocyanides and other substances has led to the view that the properties of these compounds can best be explained on the assumption that they contain a bivalent carbon atom. The evidence is clear in the case of the isocyanides. Certain of these compounds unite with two atoms of chlorine and form addition products: $RNC.Cl_2$. If the union is possible as the result of a state of unsaturation between the nitrogen and carbon atom, the structure of the addition product should be represented by the formula



It will be recalled that when addition takes place to unsaturated compounds which are represented as containing a double or triple bond, the reaction takes place in such a way that atoms or groups are added to the adjacent

atoms between which the state of unsaturation exists. This is represented by the formulas which are already familiar:

$$H_2C{=}CH_2 \longrightarrow H_2C(Br){-}CH_2(Br), \qquad CH_3C(H){=}O \longrightarrow CH_3C(H)(SO_3Na){-}OH$$

When chlorine is added to an isocyanide, however, the two atoms unite directly with carbon. The structure of the addition products must be represented by the formula $RNC\langle^{Cl}_{Cl}$. This is shown by the fact that when these addition products are treated with silver oxide the halogen atoms are replaced by oxygen and an isocyanate, R—N=C=O, is formed. The structure of the isocyanates has been established by a study of their properties. It follows, therefore, that in the isocyanides the unsaturation must be traced to a *single* element and is not, as in most cases, the result of a mutual relation between two elements. The formula may be written, therefore, R—N=C=, to emphasize the fact that the carbon atom is unsaturated. It is written, however, R—N=C and the carbon is said to be bivalent. Unsaturation of a single element is common in inorganic chemistry. In phosphorus trichloride, for example, phosphorus is unsaturated in that it can unite with two chlorine atoms and form phosphorus pentachloride. Such compounds are rarely, however, spoken of as unsaturated. The distinction is drawn by assigning different valences to the atoms in the different compounds. Thus phosphorus trichloride is $P{\equiv}Cl_3$, and phosphorus is said to be trivalent; in the pentachloride it is pentavalent.

Many reactions of organic compounds can best be interpreted by the assumption that carbon may, under certain circumstances, exist in the bivalent condition. We have a striking case in carbon monoxide. Although the graphic symbol of this compound may be written C≡O, its properties are better in accord with the view that it contains a bivalent carbon atom, C=O. For example, it reacts with chlorine and forms carbonyl chloride in which the chlorine atoms are joined to carbon:

$$O{:}C + Cl_2 = O{:}C\langle^{Cl}_{Cl}$$

It is true that recent work in organic chemistry has led to the discovery of compounds in which oxygen shows a valence of 4, and the formula C≡O is, therefore, not unreasonable. Nevertheless, the view that in carbon monoxide carbon is bivalent is more in accord with the facts. The hydrolysis of hydrocyanic acid can be interpreted as the addition of water at the N=C linking:

$$H{-}N{=}C + 2H_2O = NH_3 + HCOOH$$

The poisonous properties of the hydrocyanic acid and the isocyanides may be associated, as in the case of carbon monoxide, with the presence of a bivalent carbon atom.

Cyanic Acid and Related Compounds

252. Cyanic acid, H—O—C≡N or H—N=C=O, is prepared by heating cyanuric acid, which is described below, and condensing the gas formed in a freezing mixture:

$$H_3O_3C_3N_3 = 3HOCN$$

It is a strongly acid, unstable liquid, which polymerizes rapidly above 0° to a substance called cyamelide. As the aqueous solution of the acid decomposes into carbon dioxide and ammonia:

$$HOCN + H_2O = NH_3 + CO_2$$

it cannot be prepared by the action of an acid on a cyanate.

Esters of isocyanic acid of the general formula RN=C=O can be prepared by the action of alkyl halides on silver cyanate. They have a stifling odor, polymerize readily, and react with water in the presence of alkalies and yield amines and carbon dioxide; for example:

$$CH_3N{=}C{=}O + H_2O = CH_3NH_2 + CO_2$$

253. Potassium cyanate, KOCN, is formed by the slow oxidation of potassium cyanide in the air. It is prepared by heating potassium cyanide with lead oxide:

$$KCN + PbO = KOCN + Pb$$

When the reaction is complete the cyanate is extracted from the mass by dilute alcohol. On evaporation it is obtained as a crystalline powder which is readily soluble in water. In aqueous solution the salt is hydrolyzed:

$$KOCN + 2H_2O = NH_3 + KHCO_3$$

It will be recalled that ammonium cyanate spontaneously rearranges into urea (**227**).

254. Cyanuric acid, $(CNOH)_3$, is obtained by the action of water on cyanuric chloride, $C_3N_3Cl_3$, which results from the polymerization of cyanogen chloride, CNCl. It is also obtained when urea is heated to a high temperature:

$$3CO(NH_2)_2 = (CNOH)_3 + 3NH_3$$

It is a crystalline, tribasic acid and forms well-characterized salts.

255. Fulminic Acid, C=N—OH.—Salts of this acid a obtained when nitric acid, alcohol, and mercury or silver a brought together in certain proportions. Mercuric fulminat $(CNO)_2Hg$, is prepared for use in percussion caps, which a used to explode gunpowder, dynamite, and other explosive Free fulminic acid is a very unstable volatile liquid. It reser bles closely hydrocyanic acid in odor and poisonous propertie

CHAPTER XIII

HALOGEN COMPOUNDS

256. The halogen derivatives of the hydrocarbons are of the greatest value in the synthesis of organic compounds. The methods of preparing these substances vary with the element or group to be replaced by the halogen atom, and with the element with which the latter is brought into combination. Their activity, as determined by their ability to enter into reaction with other substances, is determined by the chemical nature of the group to which the halogen is joined. The halogen compounds thus illustrate many of the important principles of organic chemistry and the effect of structure on chemical reactivity.

Alkyl Halides

The alkyl halides form a homologous series which is unusually complete. The physical properties of some of the halides which possess the normal structure are given in the following table:

Normal Alkyl Halides

Name	Chloride		Bromide		Iodide	
	Boiling point, °C.	Density, $\frac{20°}{4°}$	Boiling point, °C.	Density, $\frac{20°}{4°}$	Boiling point, °C.	Density, $\frac{20°}{4°}$
Methyl...	−23.7	0.920	4.6	1.732	42.6	2.279
Ethyl....	12.2	0.910	38.0	1.430	72.2	1.933
Propyl...	46.6	0.890	70.9	1.353	102.4	1.747
Butyl....	78.0	0.884	101.6	1.275	127	1.617
Amyl.....	105.7	0.883	127.9	1.223	156	1.517
Hexyl....	134	0.872	156	1.173	180	1.441
Heptyl...	159.5	$0.881^{16°}$	178.8	$1.133^{16°}$	203.8	$1.401^{0°}$
Octyl.....	184.6	$0.879^{15°}$	204	$1.116^{16°}$	225.5	$1.341^{14.5°}$

It is seen that the boiling points increase with increasing molecular weight and, for the halides with a given number of

carbon atoms, with the increase in the atomic weight of th halogen. The specific gravities of the chlorides are less tha one, those of the bromides and iodides greater than one. Th specific gravities of the compounds with any halogen decreas with increase in molecular weight. The alkyl halides ar insoluble in water, but dissolve in alcohol and ether, with whic the lower members are miscible in all proportions. They ar insoluble in concentrated sulphuric acid, and have a sweetis odor. The halides are colorless, but as the iodides decompos slowly on standing, a sample of an iodide which has been kep for some time is colored brown by the dissolved iodine formed The lower alkyl halides burn with a green flame.

The reactivity of the normal alkyl halides varies with th halogen and with the alkyl group; the more reactive are thos with the smaller number of carbon atoms. The iodides are th most reactive, the chlorides the most inert. Methyl iodide i much used in organic syntheses, as it reacts readily with many substances and serves as a means of introducing the methy group into such compounds. An alcoholic solution of methy iodide reacts with a similar solution of silver nitrate in the cold and silver iodide is formed. With ethyl iodide the reaction proceeds much more slowly, and with the higher alkyl iodides the application of heat is necessary to bring about reaction.

257. In the following table are given the physical properties of the isomeric butyl halides:

BUTYL HALIDES

Name	Chloride		Bromide		Iodide	
	Boiling point, °C.	Density, $\frac{20°}{4°}$	Boiling point, °C.	Density, $\frac{20°}{4°}$	Boiling point, °C.	Density, $\frac{20°}{4°}$
n-Butyl	78.0	0.884	101.6	1.275	127	1.617
Isobutyl	68.9	0.875	91.5	1.264	120.4	1.605
sec.-Butyl	68	0.871	91.3	$1.251\frac{25°}{4°}$	117.5	1.595
tert.-Butyl	51	0.840	73.3	1.222	100	1.571

The effect of structure on the boiling point is clearly shown. The halides which contain the tertiary radicals boil at the lowest temperatures and have the smallest specific gravities.

258. Preparation of Alkyl Halides.—The members of the three classes of alkyl halides—those which contain primary, secondary, and tertiary radicals, respectively—may be prepared in general by the same methods, although the method which is best adapted to a particular case often varies with the class to which the halide belongs.

Primary alkyl chlorides may be prepared by heating an alcohol with a mixture of concentrated hydrochloric acid and zinc chloride. In the case of bromides and iodides the addition of zinc chloride to the strong aqueous solution of the acid is not necessary.

It is convenient in some cases to set free the acid from a salt in the presence of the alcohol. Ethyl bromide, for example, is conveniently prepared by distilling a mixture of alcohol, potassium bromide, and sulphuric acid. It is evident that this method is limited in its application to those alcohols which are not readily converted into unsaturated hydrocarbons by sulphuric acid.

The method of replacing a hydroxyl group by a halogen atom which is most general in its application, is that in which the compound containing this group is treated with a halide of phosphorus. These reactions have also been described in Sec. **72.** It should be noted that reactions take place other than those which lead to the formation of the alkyl halide. In the preparation of alkyl bromides and iodides by this method it is not necessary to use halides of phosphorus which have been prepared previously. Red phosphorus is added to the alcohol, and bromine or iodine is then cautiously added. The phosphorus halide formed interacts with the alcohol. After standing for some time the mixture is distilled. Ethyl iodide is conveniently prepared in this way.

The *secondary alkyl halides* can be prepared from the alcohols by the action of the halogen acids or the phosphorus halides. In certain cases they can be made by adding the hydrogen halide to unsaturated hydrocarbons. Addition takes place most readily with hydriodic acid. Secondary butyl iodide, for example,

can be prepared in this way from butylene and a strong aqueo solution of hydriodic acid:

$$CH_3.CH_2.CH:CH_2 + HI = CH_3.CH_2.CHI.CH_3$$

Certain secondary alkyl halides are most readily prepare from polyhydroxy alcohols. The formation of isopropyl iodi from glycerol has been noted (**99**). Secondary hexyl iodide prepared in the same way from mannitol. The equations f the two reactions are:

$$CH_2OH.CHOH.CH_2OH + 5HI = CH_3.CHI.CH_3 + 2I_2 + 3H_2O$$

$$CH_2OH(CHOH)_4CH_2OH + 11HI = CH_3(CH_2)_3CHICH_3 + 5I_2 + 6H_2O$$

The *tertiary alkyl halides* are most readily prepared by treatin the corresponding alcohols with strong aqueous solutions of th hydrogen halide. They can also be prepared by the additio of the halogen acids to unsaturated hydrocarbons. Tertiar butyl bromide, for example, may be formed by the addition hydrobromic acid to isobutylene:

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>C:CH_2 + HBr = \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>C.Br.CH_3$$

Alkyl chlorides or bromides are formed as the result of th action of chlorine or bromine on the paraffins, but the reactio is not used in the preparation of pure compounds. In genera a mixture of substitution products is obtained. Thus pentan with chlorine yields chlorides of the structure $CH_3(CH_2)_3CH_2C$ and $CH_3(CH_2)_2CHCl.CH_3$ together with other substitutio products. The replacement of hydrogen joined to carbon b chlorine or bromine is facilitated by sunlight and catalyti agents. Iodine does not react with the paraffins (**22**).

259. The chlorination of paraffin hydrocarbons has been studied recentl with the hope that natural gas and petroleum might prove a source fo halogen derivatives of value in the arts. It has been shown, for exampl that when a mixture of five volumes of methane and four volumes of chlorin is heated to about 280° and passed over clay covered with aluminium chlorid there can be obtained from 1,000 cubic feet of the hydrocarbon about 5 pounds of carbon tetrachloride and 190 pounds of chloroform.

Amyl alcohols are produced on a large scale from compounds prepared b chlorinating the pentanes obtained from petroleum (**80**). One of the mos important problems before technical organic chemists is the utilization o petroleum as a raw material in the manufacture of useful compounds.

260. Reactions of Alkyl Halides.—Halogen atoms in organic compounds enter into reactions with many substances. When the alkyl halides are brought into contact with the more active metals, either the halogen atom is removed and a condensation product formed, or addition takes place. The two classes of reactions are illustrated by those which take place between methyl iodide and sodium and magnesium:

$$2CH_3I + 2Na = CH_3—CH_3 + 2NaI.$$

$$CH_3I + Mg = Mg\begin{matrix}CH_3\\ I\end{matrix}$$

Reactions of these types are of importance. The first (*Wurtz reaction*) is used in the preparation of hydrocarbons; the second is the first step in many important syntheses (*Grignard reaction*).

It is probable that when sodium reacts with an alkyl halide the halogen atom is first replaced by the metal, and that the compound thus formed reacts at once with another molecule of the halide:

$$CH_3I + 2Na = CH_3Na + NaI$$

$$CH_3Na + CH_3I = CH_3.CH_3 + NaI$$

When lithium reacts with butyl chloride, butyl lithium, C_4H_9Li, is formed. The compound can be isolated; it reacts with butyl chloride and forms octane.

The alkyl halides react not only with metals in the free condition, but when they are present in compounds. Many such reactions have been discussed. The equations for a few are repeated here:

$$CH_3I + NaOH = NaI + CH_3OH$$

$$CH_3I + NaOCH_3 = NaI + CH_3OCH_3$$

$$CH_3I + NaOOC.CH_3 = NaI + CH_3OOC.CH_3$$

$$CH_3I + AgNO_2 = AgI + CH_3.NO_2$$

$$CH_3I + KCN = KI + CH_3CN$$

$$CH_3I + CHNa(COOC_2H_5)_2 = NaI + CH_3.CH(COOC_2H_5)_2$$

$$CH_3I + Mg\begin{matrix}I\\ CH_3\end{matrix} = MgI_2 + CH_3CH_3$$

They form addition products with ammonia and the amines:

$$CH_3I + NH_3 = CH_3NH_3I$$
$$CH_3I + N(CH_3)_3 = (CH_3)_4NI$$

The halides react with water:

$$CH_3I + HOH = CH_3OH + HI$$

They are converted into unsaturated hydrocarbons when heate with a base; a solution of potassium hydroxide in alcohol is fr quently used:

$$C_2H_5I = C_2H_4 + HI$$

The alkyl halides lose hydrogen halide when they are heate alone, but the reaction takes place at a high temperature; it catalyzed by lime.

The reactions of tertiary halides are frequently differer from those of the corresponding primary compounds. Th former are readily converted into unsaturated hydrocarbons a the result of the elimination of hydrogen halide. Thus, tertiar butyl iodide when heated with ammonia does not form an amir as normal butyl iodide does, but is converted into isobutylen

Tertiary alkyl halides are hydrolyzed by water much mo rapidly than the isomeric primary or secondary compound Tertiary butyl bromide is converted slowly into the alcohol an hydrobromic acid when shaken with cold water.

261. Identification of Alkyl Halides.—On account of the relative inertness at ordinary temperatures the alkyl halides ar usually identified by the determination of their physical prope ties. They are insoluble in concentrated sulphuric acid, and unlike the acyl halides, they do not react readily with water an alcohols. Unlike the compounds in which halogen is joined t nitrogen, they are not easily changed by an aqueous solution o potassium hydroxide. They are distinguished from many halo gen derivatives of benzene and related hydrocarbons, which wi be described later, by the fact that they are decomposed whe boiled with an alcoholic solution of potassium hydroxide:

$$C_2H_5Br + KOH \text{ (in alcohol)} = C_2H_4 + KBr + H_2O$$

The presence of halogen ions, from the salt formed, may be show by adding silver nitrate to the diluted solution after it has bee acidified by the addition of nitric acid.

The specific gravity of a halide is frequently determined, as this constant, considered in connection with the boiling point of a substance, often serves to identify it. The specific gravities of the chlorine derivatives of the paraffin hydrocarbons which contain one chlorine atom, are less than one. Those of the derivatives which contain more than one chlorine atom are greater than one. The accumulation of halogen atoms in a compound results in an increase in specific gravity. Thus this constant for ethyl bromide, C_2H_5Br, is 1.430 $\frac{20°}{4°}$, and for ethylene bromide, $C_2H_4Br_2$, 2.182 $\frac{20°}{4°}$.

Unsaturated Halogen Compounds

262. The substitution products of the unsaturated hydrocarbons may be sharply divided into two classes according to their chemical properties. Those in which the halogen is joined to a saturated carbon atom form one class, and those in which it is joined to a carbon atom linked to a second carbon atom by a double or triple bond, form another. The structure of such compounds is illustrated by the isomeric bromopropenes:

$CH_2{=}CH.CH_2Br$	$CH_2{=}CBr.CH_3$	$CHBr{=}CH.CH_3$
3-bromopropene	2-bromopropene	1-bromopropene

3-Bromopropene (allyl bromide) may be formed by the methods used in the preparation of the alkyl bromides. It resembles the bromides of the saturated radicals in its conduct with other compounds. It differs from them, however, in that it is much more reactive. The other bromopropenes belong to the second class. They are comparatively inert and do not enter into reactions of double decomposition with other substances. The characteristic properties of the unsaturated halides can be illustrated best by a consideration of a few typical members.

263. Vinyl bromide, $CH_2{=}CHBr$, is prepared by the action of alcoholic potash upon ethylene bromide:

$$CH_2Br.CH_2Br + KOH \text{ (in alcohol)} = CH_2{:}CHBr + KBr + H_2O$$

It is a liquid of ethereal odor, which boils at 15.8°, and has the specific gravity 1.517 at $\frac{14°}{4°}$. It is polymerized by the action of sunlight into a white mass which is insoluble in alcohol and ether. It shows but few of the reactions which are characteristic of the saturated halogen compounds. When treated with

an aqueous solution of an alkali, an alcohol is not formed; sodium ethylate does not yield an ether, nor sodium acetate an ester. With all these reagents vinyl bromide loses hydrogen bromide and acetylene is formed:

$$CH_2:CHBr = CH{\equiv}CH + HBr$$

264. 3-Bromopropene (allyl bromide), $CH_2{=}CH.CH_2Br$, can be prepared by treating allyl alcohol with hydrobromic acid or phosphorus tribromide. It boils at 71.3° and has the specific gravity 1.398 at $\frac{20°}{4°}$. Allyl bromide enters into reaction readily with the different classes of compounds with which alkyl bromides react. The reactivity of the unsaturated halides of this type, as measured by the rate at which reaction with other substances proceeds, is much greater than that of the saturated halides. For example, the rate at which allyl iodide reacts with sodium ethylate and forms an ether is sixty times that at which propyl iodide reacts with the same substance.

265. 2-Bromopropene, $CH_2{=}CBr.CH_3$, (b.p. 48.4°), like other substances of this class, can be prepared from a halogen derivative of a saturated hydrocarbon, by applying the general method of preparing unsaturated compounds. It is formed from the dibromopropane of the structure $CH_3.CBr_2.CH_3$, by eliminating one molecule of hydrobromic acid:

$$CH_3.CBr_2.CH_3 = CH_2:CBr.CH_3 + HBr$$

It does not enter into reactions of double decomposition and does not add to unsaturated compounds.

266. 1-Bromopropene, $CH_3CH{=}CHBr$, (b.p. 60.2°), resembles 2-bromopropene in chemical properties. It is prepared from 1,1-dibromopropane:

$$CH_3CH_2.CHBr_2 = CH_3.CH:CHBr + HBr$$

When propylene bromide (1,2-dibromopropane) is treated with alcoholic potash a mixture of 2- and 1-bromopropene is obtained:

$$CH_3.CHBr.CH_2Br = CH_3.CH:CHBr + HBr$$

$$CH_3.CHBr.CH_2Br = CH_3.CBr:CH_2 + HBr$$

The halogen substitution products of the hydrocarbons of the acetylene series resemble those derived from hydrocarbons which contain a double bond. The derivatives of acetylene are

very unstable. Chloroacetylene is a gas which decomposes instantaneously, with explosion. The substitution products which contain the $\equiv CH$ group form precipitates with ammoniacal solutions of silver and cuprous salts.

Substitution Products of the Hydrocarbons Which Contain More than One Halogen Atom.

267. Many compounds of this class are known. A variety of methods are used in their preparation, some of the more important of which will be discussed in the consideration of a few typical compounds. The reactions of the polyhalogen derivatives of the hydrocarbons resemble, to some extent, those of the monohalogen substitution products. The accumulation of negative atoms in the molecule modifies, however, the reactivity of these compounds. The position of a halogen atom relative to a

Polyhalogen Derivatives of the Hydrocarbons C_nH_{2n+2}

Name	Formula	Melting point, °C.	Boiling point, °C.	Density, $\frac{20°}{4°}$
Methylene chloride	CH_2Cl_2	−96.7	40.1	1.336
Methylene bromide	CH_2Br_2	−52.8	97.8	$2.46^{\frac{15°}{15°}}$
Methylene iodide	CH_2I_2	5.2	180	3.325
Chloroform	$CHCl_3$	−63.5	61.2	1.489
Bromoform	$CHBr_3$	7.7	150.4	2.890
Iodoform	CHI_3	119	.....	4.1
Carbon tetrachloride	CCl_4	−23	76.8	1.595
Carbon tetrabromide	CBr_4	48.4	189.5	3.42
Carbon tetraiodide	CI_4	.....	.....	4.32
Ethylene chloride	$CH_2Cl.CH_2Cl$	−35.3	83.7	1.257
Ethylene bromide	$CH_2Br.CH_2Br$	10	131.7	2.182
Ethylene iodide	$CH_2I.CH_2I$	82	.....	$2.132^{10°}$
Ethylidene chloride	$CH_3.CHCl_2$	−96.7	57.3	1.174
Ethylidene bromide	$CH_3.CHBr_2$	.....	110	2.056
Ethylidene iodide	$CH_3.CHI_2$	.....	179	$2.84^{0°}$
Propylene chloride	$CH_3.CHCl.CH_2Cl$	.....	96.8	$1.166^{14°}$
Propylene bromide	$CH_3.CHBr.CH_2Br$	−55.5	140	1.933
1, 1-Dibromopropane	$CH_3.CH_2.CHBr_2$	.....	130	.....
2, 2-Dibromopropane	$CH_3.CBr_2.CH_3$	.....	114.5	1.783
1, 3-Dibromopropane	$CH_2Br.CH_2.CH_2Br$	−34.4	167	1.979

second halogen atom is a determining factor in the influence of the one on the reactivity of the other. Thus, while ethylene bromide, $CH_2Br.CH_2Br$, reacts more readily with other substances than does ethyl bromide, $CH_3.CH_2Br$, ethylidene bromide, $CH_3.CHBr_2$, is relatively inert and does not enter, in general, into reactions of double decomposition. In most cases the accumulation of halogen atoms about a single carbon atom leads to inertness, while the reverse is true if the halogen atoms are linked to different atoms. It would lead too far at this point to describe in detail many polyhalogen compounds, but a comparative study of the properties of these in relation to their structure might well be undertaken with profit. Some of the derivatives of methane and ethane which illustrate important principles will be discussed.

268. Methylene chloride, CH_2Cl_2, dichloromethane, is formed when chlorine acts upon methane in the sunlight. As it cannot be obtained pure in this way, it is prepared from chloroform by replacing one halogen atom by hydrogen. The replacement is effected by treating an alcoholic solution of chloroform with zinc and hydrochloric acid:

$$CHCl_3 + 2H = CH_2Cl_2 + HCl$$

269. Methylene iodide, CH_2I_2, is of interest on account of the fact that its specific gravity ($3.325^{\frac{20°}{4°}}$) is greater than that of any other liquid except mercury. It is used in separating minerals of different specific gravities. By dilution with benzene, liquids of any desired specific gravity between that of benzene, $0.878\ ^{\frac{20}{4°}}$, and methylene iodide may be obtained. Methylene iodide is prepared by heating iodoform with hydriodic acid and phosphorus:

$$CHI_3 + HI = CH_2I_2 + I_2$$

Phosphorus is usually added when reductions are effected by hydriodic acid. It combines with the iodine liberated to form phosphorus iodide, which is converted by the water present into hydriodic acid and phosphorus acid. In this way hydriodic acid is constantly regenerated.

270. Chloroform, $CHCl_3$, trichloromethane, is prepared on a large scale by agitating carbon tetrachloride with iron and water

for several days. The reaction resembles the reduction of chloroform to methylene chloride. Tetrachloroethylene, $CCl_2=CCl_2$, which is formed along with other compounds as a by-product is a valuable solvent.

Chloroform is also prepared by distilling an aqueous solution of alcohol or acetone with bleaching powder.

271. The reaction in this case is a complex one which is assumed to involve, in the case of alcohol: first, oxidation to aldehyde; then, substitution by which trichloroaldehyde is formed; and, finally, decomposition of the latter which produces chloroform. It will be recalled that when bleaching powder is dissolved in water the solution reacts as if it contained calcium hypochlorite and calcium chloride. The steps in the reaction between alcohol and bleaching powder may be represented by the following equations:

$$2CH_3.CH_2OH + Ca(OCl)_2 = 2CH_3.CHO + CaCl_2 + 2H_2O$$

$$2CH_3.CHO + 3Ca(OCl)_2 = 2CCl_3.CHO + 3Ca(OH)_2$$

$$2CCl_3.CHO + Ca(OH)_2 = 2CHCl_3 + (HCOO)_2Ca$$

It is possible that the reaction does not take place as indicated by the equations given above, as compounds other than chloroform are obtained. It is known, however, that when alcohol is treated with chlorine, trichloroaldehyde is formed, and that the latter with alkalies yields chloroform and a salt of formic acid.

Chloroform is formed also when acetone is distilled with bleaching powder:

$$2CH_3COCH_3 + 3Ca(OCl)_2 = 2CCl_3COCH_3 + 3Ca(OH)_2$$

$$2CCl_3COCH_3 + Ca(OH)_2 = 2CHCl_3 + (CH_3COO)_2Ca$$

The reaction, in all probability, takes place as indicated, as chloroform and calcium acetate are produced—the products formed when trichloroacetone is treated with calcium hydroxide.

The formation of chloroform from acetone is an example of a general reaction. Ketones which contain the acetyl radical, CH_3CO, are converted by bleaching powder into chloroform and the salt of an acid; thus, methyl ethyl ketone yields chloroform and a propionate:

$$2CH_3COC_2H_5 + 3Ca(OCl)_2 = 2CCl_3COC_2H_5 + 3Ca(OH)_2$$

$$2CCl_3COC_2H_5 + Ca(OH)_2 = 2CHCl_3 + (C_2H_5COO)_2Ca$$

272. *Properties.*—Chloroform is a liquid, which possesses a characteristic ethereal odor and a sweet taste. It boils at 61.2°, and when solidified melts at −63.5°. It is only very slightly soluble in water: 1 liter of a saturated solution contains about 7 grams of chloroform. It is not inflammable. Chloroform was

formerly much used as an anesthetic, but it has been replaced largely for this purpose by ether. Chloroform is an excellent solvent for many organic substances. It dissolves rubber and fats, and is a useful cleansing agent.

Chloroform slowly undergoes decomposition when exposed to air and light. Among the products formed are chlorine, hydrochloric acid, and carbonyl chloride, $COCl_2$. The presence of about 1 per cent of alcohol prevents, to a large extent, the decomposition. Chloroform should be kept in the dark or in a bottle of nonactinic glass.

When chloroform is warmed with a dilute solution of an alkali it is converted into a salt of formic acid:

$$CHCl_3 + 3NaOH = 3NaCl + CH(OH)_3$$

$$CH(OH)_3 = HCOOH + H_2O$$

The accumulation of negative atoms around the single carbon leads to an activation of the chlorine atoms; the halogen atoms in chloroform are more reactive than the chlorine in methyl chloride. When chloroform is heated with a strong aqueous solution of potassium hydroxide (about 40 per cent) carbon monoxide is formed.

273. A compound of chloroform and acetone, known in pharmacy as *chloretone*, is used as a hypnotic. It is formed from chloroform and acetone in the presence of potassium hydroxide. The structure of the addition product is probably analogous to that of other such derivatives of acetone:

$$(CH_3)_2C\begin{matrix}OH\\ \diagup\\ \diagdown\\ CCl_3\end{matrix}$$

Chloroform undergoes oxidation when heated with a mixture of sulphuric acid and potassium dichromate. The reaction serves as a means of preparing carbonyl chloride (phosgene), $COCl_2$:

$$Cl_3CH + O = Cl_3C{-}OH$$

$$\begin{matrix}Cl\\ Cl\\ Cl\end{matrix}\!\!>\!C.OH = \begin{matrix}Cl\\ \diagup\\ \diagdown\\ Cl\end{matrix}\!\!>\!C{:}O + HCl$$

When chloroform is treated with concentrated nitric acid nitrochloroform, which is commonly called *chloropicrin*, is produced:

$$CCl_3H + HONO_2 = CCl_3NO_2 + H_2O$$

The compound (m.p. −64°, b.p. 112.4°) was used in large quantities as a war gas. It is lachrymatory and poisonous. One part of the vapor of chloropicrin in 1,000,000 of air causes the flow of tears. It was prepared on a large scale by the action of a solution of bleaching powder on picric acid.

274. Iodoform, CHI_3, triiodomethane, is formed when alcohol and certain other compounds (**72**) are treated with iodine in the presence of an alkali. It can be prepared by adding iodine to a warm aqueous solution of alcohol or acetone which contains sodium carbonate. The iodoform, which separates as a yellow precipitate, is purified by crystallization from dilute alcohol. It crystallizes in yellow, lustrous, six-sided plates, which melt at 119°, and have a peculiar, very characteristic odor. The reactions by which alcohol is converted into iodoform are analogous to those as the result of which chloroform is obtained from alcohol. The formation of iodoform is often used as a test for ethyl alcohol, but as other substances, such as acetone, isopropyl alcohol, and aldehyde, yield iodoform when warmed in alkaline solution with iodine, the test is not reliable unless it is known that the other substances which respond to it are absent. Most of the compounds which yield iodoform when treated in this way contain the group $CH_3.C$ linked to oxygen.

Iodoform can be prepared economically by the electrolytic oxidation at 60° of an aqueous solution of alcohol containing potassium iodide and sodium carbonate.

Iodoform is used in surgery as an antiseptic. On account of its unpleasant odor many antiseptic preparations have been prepared in which the odor of iodoform, which most of them contain, is either disguised or eliminated. Eka-iodoform is a mixture of iodoform and paraformaldehyde; anozel, of iodoform and thymol. The so-called "diiodoform" is tetra-iodo-ethylene, C_2I_4.

275. Carbon tetrachloride, CCl_4, is the final product of the action of chlorine on methane. It is a heavy liquid which has a pleasant odor resembling that of chloroform. It boils at 76.8°, and has the specific gravity 1.595 at $\frac{20°}{4°}$. It is prepared commercially by the action of chlorine on carbon disulphide in the presence of antimony pentasulphide, which acts as a carrier:

$$CS_2 + 3Cl_2 = CCl_4 + S_2Cl_2$$

Carbon tetrachloride is an excellent solvent; mixed with gasoline or benzine it is much used for cleaning purposes. The mixture, owing to the presence of the halogen compound, is not inflammable.

A compound having the composition represented by the formula CCl_2F_2 (dichloro-difluoro-methane, b.p. $-30°$) has been recently suggested as a substance to replace sulphur dioxide in ce machines and electrical refrigerators. It is noninflammable and nontoxic and possesses excellent thermodynamic properties for this purpose.

276. Substitution Products of the Homologues of Methane.—The substitution products of the homologues of methane which contain two halogen atoms may be divided according to their structure into three classes: Those in which the halogen atoms are linked to the same carbon atom such as the compounds with the structure

$$CH_3.CHCl_2 \text{ and } CH_3.CCl_2.CH_3.$$

Those in which the halogen atoms are linked to neighboring carbon atoms such as

$$CH_2Cl.CH_2Cl \text{ and } CH_3.CHCl.CH_2Cl.$$

And, finally, those in which the atoms linked to halogen are separated by one or more carbon atoms as in

$$CH_2Cl.CH_2.CH_2Cl.$$

Compounds of the first class are usually prepared by the action of the halides of phosphorus on aldehydes or ketones. Ethylidene chloride (1,1-dichloroethane) is prepared from aldehyde in this way:

$$CH_3CHO + PCl_5 = CH_3CHCl_2 + POCl_3$$

and 2,2-dichloropropane from acetone:

$$CH_3COCH_3 + PCl_5 = CH_3CCl_2CH_3 + POCl_3$$

Most of the compounds of this class are not very reactive and are not much used in synthetic work. Some of them readily lose halogen hydride. Those of high molecular weight undergo this decomposition on distillation. In the preparation of

2,2-dichloropropane from acetone some 2-chloropropene is obtained:

$$CH_3.CCl_2.CH_3 = CH_3.CCl:CH_2 + HCl$$

277. Ethylene Bromide, $C_2H_4Br_2$.—The compounds in which the halogen is linked to neighboring carbon atoms are much used in the synthesis of other compounds, as they readily undergo reactions of double decomposition. They are most conveniently prepared by adding the halogens to unsaturated hydrocarbons. When ethylene, for example, is passed through bromine, addition takes place and ethylene bromide is formed:

$$CH_2:CH_2 + Br_2 = CH_2Br.CH_2Br$$

When zinc is added to an alcoholic solution of ethylene bromide, ethylene is rapidly evolved:

$$CH_2Br.CH_2Br + Zn = ZnBr_2 + CH_2:CH_2$$

When boiled with an aqueous solution of potassium hydroxide, vinyl bromide and glycol are formed:

$$CH_2Br.CH_2Br + KOH = CH_2:CHBr + KBr + H_2O$$
$$CH_2Br.CH_2Br + 2KOH = CH_2OH.CH_2OH + 2KBr$$

When the reaction is carried out in alcoholic solution, some acetylene is also formed:

$$CH_2Br.CH_2Br + 2KOH = CH{\equiv}CH + 2KBr + 2H_2O$$

Ethylene bromide reacts slowly with boiling water to form glycol:

$$CH_2Br.CH_2Br + 2HOH = CH_2OH.CH_2OH + 2HBr$$

It should be noted that these reactions are analogous to those which take place between alkyl halides and water and alkalies. The effect of the presence of two halogen atoms is to make it possible for the reactions to take place much more rapidly and at a lower temperature. Other reactions in which ethylene bromide resembles the alkyl halides are those which take place with ammonia and potassium cyanide:

$$CH_2Br.CH_2Br. + 2NH_3 = CH_2NH_2.CH_2NH_2.2HBr$$
$$CH_2Br.CH_2Br + 2KCN = CH_2CN.CH_2CN + 2KBr$$

In this way diamines and the nitriles of dicarboxylic acids may be prepared.

278. Trimethylene bromide (1,3-dibromopropane), $CH_2Br.CH_2.CH_2Br$, and other members of this class are prepared by adding halogen acids to unsaturated compounds. When allyl bromide is treated with hydrobromic acid two compounds are formed:

$$CH_2:CH.CH_2Br + HBr = CH_2Br.CH_2.CH_2Br$$
$$CH_2:CH.CH_2Br + HBr = CH_3.CHBr.CH_2Br$$

The relation between the quantities of trimethylene bromide and propylene bromide obtained is determined by the concentration of the acid and the temperature at which the reaction is carried out. With a saturated aqueous solution of hydrobromic acid, and at a temperature below 30°, the product formed consists largely of 1,3-dibromopropane. Trimethylene bromide enters into reactions of double decomposition; for example, with water it yields trimethylene glycol, $CH_2OH.CH_2.CH_2OH$.

279. Acetylene tetrachloride (symmetrical tetrachloroethane), $CHCl_2.CHCl_2$, (b.p. 146.3°) is prepared by the addition of chlorine to acetylene. Under ordinary conditions the reaction is a very energetic one which may lead to explosions. If the gases are brought together in a container filled with sand, or other porous material, the addition takes place smoothly as the heat generated is absorbed. Antimony pentachloride is at times used as a catalyst. Acetylene tetrachloride is a particularly valuable solvent for cellulose acetate and is used when the latter is made into films, varnishes, etc. It is used in the preparation of unsaturated chlorine compounds which have recently been applied as commercial solvents.

When acetylene tetrachloride is suspended in water and treated with zinc, two chlorine atoms are removed, the water becomes hot, and *dichloroethylene*, $CHCl{=}CHCl$, (b.p. 55°) distills off. When the tetrachloride is boiled with milk of lime, or passed over barium chloride heated at 350°, hydrogen chloride is eliminated and *trichloroethylene*, $CCl_2{=}CHCl$, (b.p. 88°) is formed. The compound is an efficient solvent for fat; it does not attack metals and does not produce hydrochloric acid slowly in contact with water. For these reasons it is preferred to carbon tetrachloride for many uses.

Acyl Halides

280. When the organic acids are treated with the halides of phosphorus the hydroxyl group which they contain is replaced by a halogen atom. The compounds formed react readily with other substances, and are much used in synthetic work and in the study of the structure of substances of unknown constitution. The acyl chlorides are used for these purposes and not the iodides, as in the case of the alkyl halides. The chlorides are very reactive substances. The bromides and iodides are of minor importance and have not been very fully investigated.

The first member of the series of acyl chlorides is acetyl chloride, CH_3COCl. Formyl chloride does not exist at ordinary temperatures. When an attempt is made to prepare it by the reactions which yield acyl chlorides, carbon monoxide and hydrochloric acid are obtained:

$$HCOCl = HCl + CO$$

281. Physical Properties of Acyl Chlorides.—Acetyl chloride and its homologues with small molecular weight are colorless liquids of penetrating odor, which fume in the air as the result of the formation of hydrogen chloride. The acyl chlorides boil at lower temperatures than the corresponding acids from which they are prepared. Thus, the boiling point of acetyl chloride is 52° and of acetic acid 118.1°. The replacement of the hydroxyl group in an alcohol by chlorine produces a similar effect on the boiling point. Ethyl alcohol boils at 78.5°, ethyl chloride at 12.2°. The acyl chlorides of high molecular weight can be distilled without decomposition only under diminished pressure. They are solids which may be crystallized from ether. Stearyl chloride melts at 23° and boils at 215° under a pressure of 15 mm. The acyl chlorides are insoluble in water, but those derived from the soluble acids rapidly pass into solution when treated with water, as the result of hydrolysis by which the acid and hydrochloric acid are formed.

282. Preparation of Acyl Chlorides.—Acetyl chloride and its homologues may be prepared by the action of phosphorus pentachloride on the fatty acids or their salts:

$$CH_3COOH + PCl_5 = CH_3COCl + POCl_3 + HCl$$
$$CH_3COONa + PCl_5 = CH_3COCl + POCl_3 + NaCl$$

283. In the preparation of the chlorides of low molecular weight, pho phorus trichloride is usually employed as with this reagent phosphoru oxychloride, which is removed from these chlorides with difficulty on accou of its low boiling point, is not formed. Acetyl chloride is best prepared b heating a mixture of glacial acetic acid and phosphorus trichlor de at abou 40° until reaction is complete. This is shown by the separation of th mixture into two layers. The product is then distilled from a water bath and the distillate is finally redistilled. The reaction takes place essentiall according to the equation:

$$3CH_3COOH + PCl_3 = 3CH_3COCl + P(OH)_3$$

Secondary reactions take place which results in the formation of hydroge chloride and of compounds which contain the acetyl group in combinatio with phosphorus.

284. Acetyl chloride may also be prepared from anhydrou sodium acetate by treating it with phosphorus trichloride o phosphorus oxychloride. The salt is often used instead of th glacial acid on account of the fact that it can be more readil prepared, and is consequently less expensive. The reaction which take place are shown by the following equations:

$$3CH_3COONa + PCl_3 = 3CH_3COCl + Na_3PO_3$$
$$2CH_3COONa + POCl_3 = 2CH_3COCl + NaPO_3 + NaCl$$

285. Reactions of Acyl Chlorides.—Acetyl chloride and it homologues react readily *with water*, the reaction taking plac with violence in the case of those of low molecular weight:

$$CH_3CO.Cl + H.OH = CH_3CO.OH + HCl$$

The ease with which this reaction takes place, in general, sharply distinguishes acyl chlorides from alkyl chlorides. The nature of the radical determines the rate at which the hydrolysis proceeds. The acyl chlorides, which contain negative radicals resemble in their behavior with water the chlorides of the non-metallic or electronegative elements, which react rapidly with water:

$$PCl_3 + 3HOH = P(OH)_3 + 3HCl$$

It will be recalled that the alkyl halides enter into reaction with water but slowly, and that heating to a high temperature is required to effect the interchange of chlorine and hydroxyl with an appreciable speed.

Acyl chlorides react readily not only with water, but with substitution products of water which contain an alkyl radical, *i.e.* the *alcohols*. When acetyl chloride is mixed with alcohol, ethyl acetate and hydrochloric acid are formed:

$$CH_3CO.Cl + HO.C_2H_5 = CH_3CO.OC_2H_5 + HCl$$

In this reaction the acyl chlorides are sharply differentiated from the alkyl chlorides which react with alcohols at high temperatures only.

Acetyl chloride serves, therefore, as a valuable reagent to determine the presence of alcoholic hydroxyl groups in organic compounds. The general reagent for the hydroxyl group—whether joined to a positive or negative radical—is phosphorus pentachloride. The number of hydroxyl groups in any compound may be determined by a quantitative study of the reaction which takes place when it is treated with these reagents. When phosphorus pentachloride is used, each hydroxyl group is replaced by one chlorine atom. With acetyl chloride the hydrogen of each alcoholic hydroxyl group is replaced by the acetyl radical.

Acetyl chloride does not react readily with a compound which contains a hydroxyl group in combination with an acyl radical. It does react, however, *with salts of acids*, the replacement of the hydrogen of the acid by the strongly positive metal making reaction possible. It will be recalled that the anhydrides of acids are made in this way:

$$CH_3COCl + CH_3CO.ONa = (CH_3CO)_2O + NaCl$$

Acyl chlorides react *with ammonia and amines* more readily than do the alkyl chlorides:

$$CH_3COCl + NH_3 = CH_3CO.NH_2 + HCl$$
$$CH_3COCl + NH_2C_2H_5 = CH_3CONHC_2H_5 + HCl$$

Chlorides of Dicarboxylic Acids

286. The compounds of this class are prepared by the methods which are used in the preparation of the chlorides derived from the fatty acids. In certain cases they are prepared by the action of phosphorus pentachloride on the anhydrides of the acids. In their reactions with other substances they resemble the chlorides of the monobasic acids.

Carbonyl chloride, $CO.Cl_2$, (phosgene), may be considered as the chloride of carbonic acid. It is prepared by passing a mixture of carbon monoxide and chlorine over charcoal. It was named phosgene by its discoverer on account of the fact that the union of the two substances was effected as the result of the influence of light. Carbonyl chloride is a gas with a powerful, stifling odor and should be handled carefully as its inhalation produces most disagreeable effects. It can be easily condensed to a liquid which boils at 8.3° and has the specific gravity 1.392 $\frac{20°}{4°}$.

Phosgene was extensively used as a war gas, either in shells or in drums which were hurled by projectors and exploded when they struck the earth. A mixture of phosgene and liquid chlorine was allowed to escape from cylinders when a cloud attack was made. Phosgene and "mustard gas" (**414**) were the most efficient gases used during the World War. A concentration of 0.3 milligram of phosgene in 1 liter of air is toxic to animals.

Carbonyl chloride is very soluble in benzene and toluene; such solutions are frequently used in synthetic work. Carbonyl chloride reacts slowly with cold water; carbon dioxide and hydrochloric acid are formed:

$$COCl_2 + 2HOH = CO(OH)_2 + 2HCl$$

With alcohol, reaction takes place in two steps: In the cold, ethyl chloroformate, which is also called chlorocarbonic ester, is formed:

$$COCl_2 + HOC_2H_5 = ClCOOC_2H_5 + HCl$$

On long standing, or when carbonyl chloride is treated with sodium ethylate, both chlorine atoms interact and an ethereal salt of carbonic acid, ethyl carbonate, results:

$$COCl_2 + 2HOC_2H_5 = CO(OC_2H_5)_2 + 2HCl$$

Carbonyl chloride and ammonia interact to form urea:

$$COCl_2 + 2NH_3 = CO(NH_2)_2 + 2HCl$$

These reactions are characteristic of acyl chlorides. They show that carbonyl chloride is the chloride of carbonic acid.

287. Identification of Acyl Chlorides.—The reactions of acyl chlorides which are most helpful in their identification are those which take place when they are treated with water, with

alcohol, and with ammonia. Reaction takes place readily with these substances. When an acyl chloride is mixed with a small quantity of water or alcohol, hydrogen chloride is evolved. In the case of certain chlorides gentle heat is necessary to bring about reaction. The physical properties of the chloride together with those of the acid, ester, or amide prepared from it serve to complete its identification.

Compounds Which Contain a Halogen Joined to Nitrogen

288. The methods by which a halogen atom is brought into combination with nitrogen in an organic compound are the same as those which are used to effect the union of these elements in inorganic compounds. Derivatives which contain trivalent nitrogen are prepared by treating ammonia with solutions of hypochlorites, hypobromites, or hypoiodites. Ammonium salts are formed by adding a hydrogen halide to ammonia. Substitution products and addition products of the amines and amides are prepared in the same way from the derivatives of ammonia.

The substituted ammonium salts ionize when dissolved in water, and consequently the halogen which they contain may be precipitated as silver halide when they are treated with silver salt:

$$(CH_3)_3NHCl + AgNO_3 = (CH_3)_3NHNO_3 + AgCl$$

This reaction serves to distinguish compounds of this class from other halogen substitution products. Compounds which contain at least one hydrogen atom are decomposed in aqueous solution by bases:

$$(CH_3)_3NHCl + KOH = KCl + H_2O + (CH_3)_3N$$

289. Methyl-dichloramine (*N*-dichloromethylamine), CH_3NCl_2, is prepared by treating methylamine with bleaching powder. It is liquid, insoluble in water, which possesses a characteristic, disagreeable odor. It boils without decomposition at 59° to 60°. This fact is of interest as nitrogen chloride, NCl_3, explodes violently when heated. The halogen is not converted into an ion when methyl-dichloramine is treated with water. The substance is readily decomposed by reagents. When heated with concentrated hydrochloric acid, for example, chlorine and methylammonium chloride are formed:

$$CH_3NCl_2 + 3HCl = 2Cl_2 + CH_3NH_2HCl$$

Other members of this class of compounds take part in an analogous reaction, which is, therefore, of value in the identification of such substances.

290. *N*-Bromoacetamide, $CH_3CO.NHBr$, is prepared by adding to mixture of acetamide and bromine, in the proportion of their molecula weights, a 10 per cent solution of potassium hydroxide until a colorles solution is obtained. A hydrate of the bromoamide separates in colorles crystals, $CH_3CONHBr.H_2O$. At 50° water is lost, and the anhydrou compound which melts at 108° is obtained. The substance is very reactive ammonia and amines convert it into acetamide. Silver carbonate remove hydrogen bromide and methyl isocyanate is formed:

$$CH_3CONHBr = CH_3NCO + HBr$$

When warmed with an aqueous solution of an alkali, *N*-bromoacetamide i converted into methylamine (Hofmann's reaction):

$$CH_3CONHBr + 3KOH = CH_3NH_2 + KBr + K_2CO_3 + H_2O$$

***N*-Dibromoacetamide,** CH_3CONBr_2, is obtained from *N*-bromoacetamid by the action of bromine and sodium hydroxide. It forms golden-yellow crystals, which melt at 100°; it undergoes decomposition when heated with water and is changed into acetamide.

Problems

1. Write equations for reactions to illustrate how a chlorine atom can be introduced into a compound in place of (*a*) a hydrogen atom linked to carbon, (*b*) a hydrogen atom linked to nitrogen, (*c*) a hydroxyl group linked to carbon, (*d*) a hydroxyl group linked to nitrogen, (*e*) an oxygen atom linked by two bonds to carbon.

2. (*a*) In what respects do alkyl halides resemble acyl halides in behavior and (*b*) in what respects do they differ? Illustrate by writing chemical equations for the reactions involved.

3. (*a*) Enumerate the physical properties that are useful in the identification of organic compounds. (*b*) What physical properties could be used to distinguish readily C_3H_7Cl from $C_2H_4Cl_2$?

4. By what physical and what chemical properties could the following be readily distinguished: (*a*) C_5H_{12} and $C_5H_{11}Br$; (*b*) C_7H_{14} and $C_2H_4Br_2$; (*c*) C_3H_7Cl and C_3H_7Br; (*d*) $BrCH_2CH_2OH$ and $BrCH_2CH_2Br$?

5. By what chemical property could the following be distinguished: (*a*) $CH_2BrCH_2CH_2Br$ and $CH_3CHBrCH_2Br$; (*b*) CH_3COCl and $ClCH_2COOH$; (*c*) $(C_3H_7)_2NCl$ and $(C_3H_7)_4NCl$; (*d*) $CH_2=CHCH_2Br$ and $CH_3CH_2CH_2Br$; (*e*) $CH_2=CBrCH_3$ and $CH_2=CHCH_2Br$; (*f*) $(ClCH_2CO)_2O$ and CH_3COCl?

6. What compounds do you expect would be formed as the result of the interaction of the following substances: (*a*) $CH_2BrCHBrCH_2Br$ and zinc; (*b*) iodoform and zinc; (*c*) $CH_2BrCOCl$ and water; (*d*) $CH_2ClCOBr$ and water; (*e*) $CH_2BrCOCl$ and sodium acetate; (*f*) $CH_2ClCOCl$ and a solution of sodium hydroxide?

CHAPTER XIV

COMPOUNDS CONTAINING TWO UNLIKE SUBSTITUENTS

291. In the previous chapters the preparation and properties of certain important classes of compounds have been discussed, and the principles which are illustrated in their transformations into one another have been emphasized. These principles are of wide application and can be employed in the preparation of compounds of more complex structure than any met with so far. For example, the method of preparing an alcohol by the treatment of an alkyl halide with water or an alkali is very general in its application. The reaction consists in the replacement of a halogen atom by a hydroxyl group, and such replacement takes place not only with alkyl halides, but with other compounds which contain halogen. Thus, chloroacetic acid can be transformed into hydroxyacetic acid by water:

$$CH_2Cl.COOH + HOH = CH_2OH.COOH$$

The compound which results in this case contains a primary alcohol group (CH_2OH) and a carboxyl group (COOH). It is, thus, an alcohol and an acid, and in its behavior with other substances it shows the characteristic properties of both classes of compounds. It may be considered as derived from methyl alcohol by the replacement of one hydrogen atom by a carboxyl group. While the compound possesses many of the chemical properties of methyl alcohol, the replacement of a hydrogen atom by a carboxyl group leads to a modification in the activity of the hydroxyl groups. In the same way, the replacement of hydrogen in acetic acid by the negative hydroxyl group makes hydroxyacetic acid a stronger acid than acetic acid, *i.e.*, it is more highly dissociated in aqueous solution.

By the application of the synthetic methods which have been described under the various classes of compounds many

substances which contain two or more unlike groups may be prepared. These compounds show the properties characteristic of the groups which they contain, but the mutual effect of one group on the activity of another in the same compound brings about changes which are marked at times.

Many substances of the greatest importance contain two or more unlike functional groups. The alcohol acids occur in nature as constituents of fruits. The amine acids and amide acids occur in fruits and vegetables, and are important products of the decomposition of nitrogenous foods. Ketone esters are much used in the preparation of other compounds. The ketone alcohols and aldehyde alcohols form the important class of substances known as carbohydrates. Only a few of the more important and typical compounds of this kind will be considered here.

Halogen Substitution Products of the Acids

292. Compounds of this class may be prepared by introducing halogen atoms into an acid, or the carboxyl group into halogen derivatives of the hydrocarbons. The former method is ordinarily used. Chloroacetic and bromoacetic acids, for example, may be prepared by the action of chlorine or bromine on acetic acid in the sunlight, or in the presence of a carrier (catalytic agent), such as iodine or sulphur:

$$CH_3COOH + Cl_2 = CH_2Cl.COOH + HCl$$

Iodoacetic acid cannot be prepared from acetic acid and iodine. The compound is made by digesting a strong aqueous solution of chloroacetic acid with potassium iodide.

293. As the introduction of a halogen into an acyl halide takes place more rapidly than into the acid itself, the substitution products of the fatty acids are more conveniently prepared by the action of chlorine or bromine on acyl halides. It is not necessary to isolate the latter; the acid to be brominated, for example, is mixed with red phosphorus, heated at about 80°, and bromine is slowly added. The phosphorus bromide first formed interacts with the acid to form the acyl bromide, which is converted by the free bromine present into a bromoacyl bromide. The latter yields with water the halogen substitution product of the acid:

$$CH_3COOH \xrightarrow{PBr_3} CH_3CO.Br \xrightarrow{Br_2} CH_2Br.COBr \xrightarrow{H_2O} CH_2Br.COOH$$

The temperature at which the reaction is carried out and the proportion of bromine used determine the number of bromine atoms introduced. Thus, propionic acid when treated at 100° with phosphorus and bromine gives α-bromopropionic acid, $CH_3CHBr.COOH$; and at 220° with an excess of bromine, α,α-dibromopropionic acid, $CH_3CBr_2.COOH$.

294. *Direct chlorination or bromination of the fatty acids produces, in general, α-substitution products. The acids which contain a halogen atom in the β-position are frequently prepared by adding a hydrogen halide to an unsaturated acid.* Thus β-bromopropionic acid is formed from acrylic acid and hydrobromic acid:

$$CH_2:CH.COOH + HBr = CH_2Br.CH_2COOH$$

Halogen-substituted acids are also prepared by the action of the halides of phosphorus on hydroxy acids; hydroxyacetic acid, $CH_2OH.COOH$, for example, is converted into chloroacetyl chloride by phosphorus pentachloride, both hydroxyl groups taking part in the reaction. The substituted acetyl chloride reacts readily with water and chloroacetic acid and hydrochloric acid are formed:

$$CH_2OH.COOH \xrightarrow{PCl_5} CH_2Cl.COCl \xrightarrow{H_2O} CH_2Cl.COOH$$

Derivatives of the acids which contain more than one halogen atom are prepared by substitution at high temperatures in the presence of a carrier or in the sunlight. They may also be formed *by the addition of the halogens to unsaturated acids:*

$$CH_2:CH.COOH + Br_2 = CH_2Br.CHBr.COOH$$

295. Reactions of the Halogen Derivatives of the Fatty Acids.—The introduction of halogen atoms, which are negative, into the acids causes a marked increase in their strength. The relative effect of the three halogens and of their position in the molecule on the strength of the acids, will be considered in detail in connection with other derivatives of the acids (**362**). On the other hand, the presence of the carboxyl group has a marked effect on the reactivity of the halogen atoms which these acids contain. The effect varies with the relative position of the halogen and the carboxyl group.

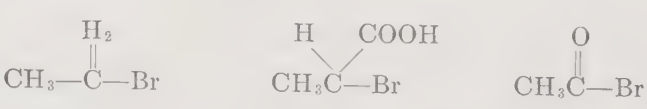
With Water.—When an acid which contains a halogen atom in the α-position is boiled with an aqueous solution of an alkali, the halogen atom is readily replaced by hydroxyl:

$$CH_3CHBr.COOH + 2KOH = CH_3CHOH.COOK + KBr + H_2O$$

296. This reaction is analogous to that by which ethyl bromide is converted into alcohol:

$$CH_3CH_2Br + KOH = CH_3CH_2OH + KBr$$

It differs from it, however, in that, while the alkyl halide must be heated for hours at a high temperature to effect the exchange of halogen for hydroxyl, the same transformation takes place with the halogen-substituted acid at a lower temperature and in less time. This difference is produced as the result of the presence of the negative carboxyl group. In the discussion of the relative reactivity of alkyl and acyl halides, it was pointed out that the marked difference between these two classes of compounds in this respect could be traced to the difference in the composition of the radicals which they contained. The replacement of two positive hydrogen atoms by one negative oxygen atom resulted in a marked change in properties. In the same way, we may consider α-bromopropionic acid as derived from ethyl bromide by replacing one hydrogen atom by a carboxyl group. The formulas of the three compounds written to emphasize these relationships are as follows:



From this point of view we should expect the reactivity of the halogen in the substituted acid to stand somewhere between that of the halogen in the alkyl halide and that in the acyl halide.

297. *When the halogen atom in an acid is in the β-position, the compound may yield, when heated with water or alkalies, a hydroxy acid, an unsaturated acid, or a hydrocarbon.* In certain cases all three substances are formed. It is sometimes possible, by selecting the proper reagents, to vary the proportions in which the resulting substances are formed. When the acids are heated with water or with an alcoholic solution of potassium hydroxide, the chief product is an unsaturated acid:

$$CH_3CHBr.CH_2COOH = CH_3.CH:CH.COOH + HBr$$

On the other hand, when they are warmed with a solution of an alkali carbonate, an unsaturated hydrocarbon also may be formed:

$$CH_3.CHBr.CH(CH_3)COONa = CH_3.CH:CH.CH_3 + NaBr$$

All of these reactions are analogous to ones which have been described, namely, the replacement of halogen by hydroxyl, the formation of an unsaturated compound by elimination of halogen hydride, and the decomposition of a salt of a fatty acid with the resulting formation of a hydrocarbon. This last decomposition takes place in the case of the fatty acids only on heating their salts to a comparatively high temperature with an alkali:

$$CH_3COONa + NaOH = CH_4 + Na_2CO_3$$

It is seen in the case of the β-halogen-substituted acids, that an analogous decomposition takes place in water solution at or below the boiling point. Other acids which contain groups more negative than the alkyl radicals undergo a similar decomposition very readily. For example, when trichloroacetic acid is boiled with water and an alkali, chloroform is formed:

$$CCl_3COONa + NaOH = CCl_3H + Na_2CO_3$$

The γ-halogen-substituted acids react readily with boiling water and form first, hydroxy acids, which, being unstable, lose one molecule of water and pass into substances known as lactones (**306**).

A brief description of only a few typical halogen-substituted acids will be given to emphasize the principles which have been set forth.

298. Chloroacetic acid, $CH_2Cl.COOH$, is prepared by the chlorination of acetic acid, acetyl chloride, or acetic anhydride in direct sunlight in the presence of iodine, which acts as a halogen carrier, or by passing chlorine into a boiling mixture of 1 part of sulphur and 10 parts of acetic acid. The product obtained is purified by fractional distillation. Chloroacetic acid melts at 61.2°, boils at 189.5°, and is readily soluble in water. The acid produces painful blisters on the skin, and its vapor attacks the eyes causing tears. The halogen atom which the acid contains can be replaced by other atoms or groups. A salt of aminoacetic acid is prepared from the acid and ammonia:

$$CH_2Cl.COOH + 3NH_3 = CH_2NH_2.COONH_4 + NH_4Cl$$

and hydroxyacetic acid by the action of water:

$$CH_2Cl.COOH + HOH = CH_2OH.COOH + HCl$$

Chloroacetic acid is prepared commercially for use in the synthesis of indigo, which is manufactured on a large scale.

299. Chloroformic acid, ClCOOH, does not exist; reactions which would lead to its formation yield carbon dioxide and hydrochloric acid. Esters of the acid can be formed, however, and they played an important part in the World War. The most important of them is the trichloromethyl ester, $ClCOOCCl_3$, which was used as a war gas by the French under the name "surpalite," and by the English who called it "diphosgene," since its empirical formula is $C_2O_2Cl_4$ or twice that of phosgene, $COCl_2$. The compound was made by chlorinating methyl formate, $HCOOCH_3$ under the influence of powerful actinic light. On account of its relatively high boiling point as compared with phosgene, diphosgene is a much more persistent gas than the former. Its toxicity was high; only the difficulty in its preparation limited its use.

300. Dichloroacetic acid, $CHCl_2.COOH$, can be prepared by chlorinating acetic acid, but as the acid made in this way is mixed with chloroacetic acid, it is usually prepared by boiling chloral hydrate (**347**) with an aqueous solution of potassium cyanide:

$$CCl_3CH(OH)_2 + KCN = CHCl_2.COOH + KCl + HCN$$

The acid melts at $-4°$ and boils at 193.5°.

301. Trichloroacetic acid, $CCl_3.COOH$, is most conveniently prepared by oxidizing chloral or chloral hydrate with fuming nitric acid:

$$CCl_3.CHO + O = CCl_3.COOH$$

The acid melts at 57.5° and boils at 195.3°. The decomposition which it undergoes when boiled with water and an alkali has already been noted (**297**).

302. α-Bromopropionic acid, $CH_3CHBr.COOH$, is prepared by brominating propionic acid in the presence of phosphorus. The reactions involved have been discussed (**293**). The acid melts at 25.7° and boils at 203.5°. It is readily converted into lactic acid (**308**) when heated with water or a solution of an alkali:

$$CH_3.CHBr.COOH + KOH = CH_3.CHOH.COOH + KBr$$

303. β-Iodopropionic acid can be made from acrylic acid and hydriodic acid:

$$CH_2:CH.COOH + HI = CH_2I.CH_2.COOH$$

but it is usually prepared by treating glyceric acid, $CH_2OH.CHOH.COOH$, with hydriodic acid (phosphorus, iodine, and water):

$$CH_2OH.CHOH.COOH + 3HI = CH_2I.CH_2.COOH + I_2 + 2H_2O$$

The reaction is analogous to that by which isopropyl iodide is prepared from glycerol.

304. α,β**-Dibromopropionic acid,** $CH_2Br.CHBr.COOH$, can be prepared from allyl alcohol by the reactions indicated by the following formulas:

$$CH_2:CH.CH_2OH \xrightarrow{Br_2} CH_2Br.CHBr.CH_2OH \xrightarrow{O} CH_2Br.CHBr.COOH$$

or by the action of phosphorus pentabromide on glyceric acid:

$$CH_2OH.CHOH.COOH \xrightarrow{PBr_5} CH_2Br.CHBr.COOH$$

Halogen substitution products of the unsaturated monocarboxylic acids and of the unsaturated and saturated polycarboxylic acids are known. They form an interesting group of compounds, but it would lead too far to consider them here. A few will be referred to in the discussion of other compounds.

Hydroxy Monocarboxylic Acids

305. The hydroxy acids are substitution products of the acids which contain hydroxyl groups. They may be considered, also, as derived from the alcohols by the replacement of one or more hydrogen atoms by carboxyl groups.

Preparation.—The methods used in their preparation are based on this view of their structure. They may be prepared by introducing hydroxyl groups into acids, the methods employed being similar to those used in the synthesis of alcohols; or by introducing the carboxyl group into alcohols, the methods used in this case being similar to those applied in the preparation of acids. The more important of these methods are well illustrated by various syntheses of α-hydroxy-propionic acid (lactic acid), which can be prepared by the following methods:

1. By the action of water on a halogen-substituted acid:

$$CH_3.CHBr.COOH + HOH = CH_3.CHOH.COOH + HBr$$

2. By the action of nitrous acid on an amino acid:

$$CH_3.CHNH_2.COOH + HNO_2 = CH_3.CHOH.COOH + N_2 + H_2O$$

3. By the limited oxidation of a polyhydroxy alcohol which contains a primary alcohol group:

$$CH_3.CHOH.CH_2OH + 2O = CH_3.CHOH.COOH + H_2O$$

4. By the hydrolysis of the addition products of aldehydes and ketones with hydrocyanic acid:

$$CH_3.CHO \xrightarrow{HCN} CH_3C(H)(OH)(CN) \xrightarrow{HOH} CH_3.CHOH.COOH$$

5. By the reduction of compounds which contain, in addition to a carboxyl group, a carbonyl group:

$$CH_3.CO.COOH + 2H = CH_3.CHOH.COOH$$

The *reactions of the hydroxy acids* are, in general, those of both alcohols and acids. For example, they form salts and esters; they react with the halides of phosphorus, and the hydroxyl groups are replaced by halogen; the hydrogen of both the alcoholic and acidic hydroxyl groups may be replaced by sodium; they form ethers by the replacement of the hydrogen of the alcoholic group by alkyl radicals; and so forth.

The hydroxy acids decompose with loss of water with greater or less ease. The readiness with which the decomposition takes place, and the nature of the compound formed, are determined by the relative positions of the hydroxyl and carboxyl groups.

306. The *α-Hydroxy acids* are decomposed when heated. Glycolic acid, $CH_2OH.COOH$, for example, yields glycolide:

$$\underset{\text{Glycolic acid}}{CH_2O\,H\,HO\,CO \;\; OC\,OH\,H\,OH_2C} = \underset{\text{Glycolide}}{CH_2{-}O{-}CO \;\; OC{-}{-}O{-}CH_2} + 2H_2O$$

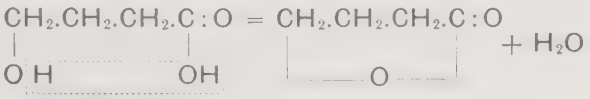
Two molecules of acid react with each other, and water is formed as the result of the interaction of the alcoholic hydroxyl group of one with the acidic hydroxyl group of the other. The resulting compound is, therefore, an ester. This is shown by the fact that the substances formed in this way from α-hydroxy acids

are readily hydrolyzed when heated with water or a solution of an alkali, and the corresponding acid is reformed.

β-Hydroxy acids readily lose water when heated alone or in the presence of a dehydrating agent, and form unsaturated acids. In this way acrylic acid is formed from β-hydroxypropionic acid:

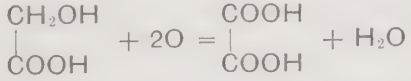
$$CH_2OH.CH_2.COOH = CH_2:CH.COOH + H_2O$$

γ-Hydroxy acids and δ-hydroxy acids lose water with the greatest ease and form *lactones*. Some of these acids are so unstable that when they are liberated from their salts they pass spontaneously by loss of water into lactones. The lactones are inner esters formed as the result of the interaction of the alcoholic and acidic hydroxyl groups which the hydroxy acids contain:

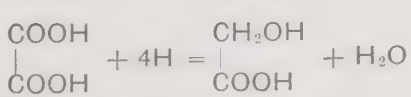


Most lactones are hydrolyzed when heated with water; the equation last given is that of a reversible reaction. A few typical hydroxy acids will be considered in some detail.

307. Glycolic acid, $CH_2OH.COOH$, which is hydroxyacetic acid, occurs in unripe grapes. It is a crystalline solid, which melts at 79° and is readily soluble in water. It is formed, along with other substances, as the result of the oxidation of alcohol and glycol by nitric acid, and of various sugars by silver oxide. Glycolic acid is oxidized by nitric acid to oxalic acid:



Oxalic acid on reduction with sodium amalgam yields glycolic acid:



308. Lactic acid, $CH_3.CHOH.COOH$, α-hydroxypropionic acid, exists in three forms, two of which are optically active. The acid contains an asymmetric carbon atom and its optical

activity is traced to this cause as in the case of amyl alcoh which has been considered at some length (**81**).

Inactive lactic acid results when lactic acid is prepared by t synthetic methods which have been mentioned (**305**). T inactive acid may be separated into its constituents by the u of certain general methods which have been found applicable such cases. While the salts of the dextro and levo forms active acids with a metallic element have the same solubility, a cannot, therefore, be separated by crystallization, the sal formed from these acids and certain organic bases which a optically active differ in solubility. By the fractional cry tallization of the strychnine salt of inactive lactic acid, two sal can be separated. The acids obtained from these differ in the action on polarized light; one is dextrorotatory, *d*-lactic aci and the other levorotatory, *l*-lactic acid. The inactive form *dl*-lactic acid.

An active form of an acid may be obtained from the inactiv variety by subjecting it to the action of certain bacteria, whic destroy one form of the acid more rapidly than the other. I the case of lactic acid the dextro form may be obtained by th action of the mould called *Penicillium glaucum* on inactiv ammonium lactate. When lactic acid is made by the ferment tion of milk sugar, cane sugar, or glucose, the acid formed determined by the bacteria used. Under the influence of *Micr coccus acidi paralactici* the dextro acid is obtained; with *Bacill acidi laevolactici* the levo variety is formed.

309. ***dl*-Lactic acid** was discovered in 1780 by Scheele, wh isolated it from sour milk. The acid is formed as the result the action of certain bacteria which are present in the air o the sugar which milk contains. It is found in other product which have undergone fermentation, such as sauerkraut an silage, which is prepared by storing grass, clover, and othe cattle food under pressure. Lactic acid is present in the stomach intestines, and muscles. It may be prepared by the applicatio of the reactions which have been mentioned (**305**), but th methods usually employed involve the preparation of the aci by fermentation from cane sugar or from glucose.

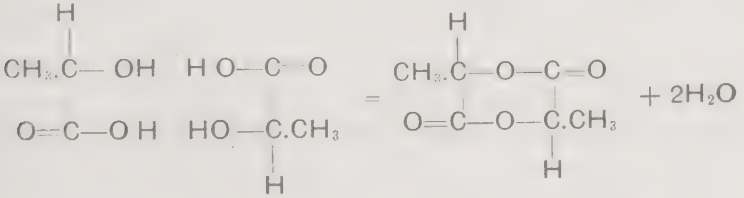
310. In one of these methods the sugar is first converted into glucose b the action of an acid. After neutralization, sour milk, decaying cheese and calcium carbonate are added, and the mixture kept for a number o

days at 40°, when fermentation takes place. The bacteria which bring about the change are present in the cheese. The milk which is added facilitates the change, as it furnishes the food which the bacteria need in their growth. The calcium carbonate is added to the mixture to keep the solution neutral, as fermentation stops when the solution contains more than 1 per cent of acid. The fermentation must not be allowed to continue for too long a time, for, as has already been mentioned (**120**), the lactic acid produced is converted by a second fermentation into butyric acid. Calcium lactate, which is formed, is purified by crystallization, and finally decomposed by sulphuric acid, when an aqueous solution of pure lactic acid is obtained.

311. Lactic acid is also formed when cane sugar or glucose is boiled with a solution of sodium hydroxide. The acid may be separated from the mixture by converting it into its calcium or zinc salt. These are purified by crystallization and the acid is obtained by treating the calcium salt with sulphuric acid, or the zinc salt with hydrogen sulphide. The reaction furnishes a convenient laboratory method of preparing the acid.

Ethyl lactate is a valuable solvent. It can be prepared by mixing acetaldehyde, sodium cyanide, ethyl alcohol, and hydrogen chloride. The hydrocyanic acid formed adds to the aldehyde; under the influence of the acid the nitrile is hydrolyzed and the resulting lactic acid reacts with alcohol and forms ethyl lactate.

312. Lactic acid, as ordinarily obtained, is a thick, colorless, odorless, hygroscopic liquid, which has the specific gravity $1.24^{\frac{20}{4^\circ}}$. It is miscible with water and alcohol, and is slightly soluble in ether. It decomposes when heated, but when distilled under a pressure of 15 mm. it boils at 122°. The liquid solidifies in a freezing mixture to crystals which melt at 18°. At 150° lactic acid loses water and *lactide* (m.p. 125°, b.p. 255°) is formed:



Lactide is an ester formed by the interaction of the alcoholic hydroxyl groups with the acidic hydroxyl groups. When boiled with water it is hydrolyzed and lactic acid is formed. When

lactic acid is heated with an aqueous solution of sulphuric acid acetaldehyde and formic acid are produced:

$$CH_3.CHOH.COOH = CH_3CHO + HCOOH$$

Lactic acid is prepared by fermentation on an industrial scale It is used in dyeing and calico printing. Antimony lactate find application as a mordant.

313. The *structure of lactic acid* is arrived at from a study of its reactions and the methods by which it may be formed The presence of two hydroxyl groups is shown by the fact tha of the six hydrogen atoms which the acid contains, *two* can b replaced by sodium. That but one of these hydroxyl groups i acidic follows from the composition of the salts of the acid When sodium lactate is formed by neutralizing the acid with sodium hydroxide, but *one* of the six hydrogen atoms is replaced by the metallic atom. When lactic acid is heated with hydriodic acid to a high temperature, propionic acid is formed:

$$CH_3.CHOH.COOH + 2HI = CH_3.CH_2.COOH + I_2 + H_2O$$

The reaction is analogous to that by which alcohols are reduced to hydrocarbons. In the case of lactic acid, it shows that the compound is a hydroxyl derivative of propionic acid. The fact that the hydroxyl group occupies the α-position is shown by the synthesis of lactic acid from α-bromopropionic acid:

$$CH_3.CHBr.COOH + HOH = CH_3.CHOH.COOH + HBr$$

314. ***d*-Lactic acid** was originally called sarcolactic acid, on account of the fact that it was isolated from flesh. It is found under certain conditions in the blood and in urine, and is a characteristic constituent of muscle. It is present in "beef extract," and can be conveniently obtained from this source It can be prepared from synthetic *i*-lactic acid by the methods which have been described (**308**). The salts of the dextro rotatory acid differ in solubility, content of water of crystallization, and in physical properties from those of the inactive acid They are levorotatory. When the acid is heated it loses its optical activity and *i*-lactic acid is formed. In general, when an optically active substance is heated it is converted into the inactive variety.

The chemical properties of *d*-lactic acid are identical with those of the inactive acid. Both acids yield the same compounds when they enter into reactions with other substances. The proofs of the structure of *i*-lactic acid, which have been given, apply in the case of *d*-lactic acid. The isomerism is to be attributed, therefore, to the space relations of the atoms. The same statements in regard to structure hold true in the case of *l*-lactic acid.

315. ***l*-Lactic acid** may be obtained by the fermentation of sugar with *Bacillus acidi laevolactici*, or from the salt obtained as the result of the fractional crystallization of the strychnine salt of *i*-lactic acid. It differs in properties from *d*-lactic acid only in its action on polarized light. The metallic salts of *l*-lactic acid can be distinguished from those of the *d*-acid only by examining their rotatory power. In most cases the chemical and physical properties of two optically active isomers are identical, except in their effect on polarized light.

316. Hydracrylic acid, $CH_2OH.CH_2.COOH$, β-hydroxypropionic acid, is isomeric with lactic acid. It can be prepared by heating by β-iodopropionic acid with water:

$$CH_2I.CH_2.COOH + HOH = CH_2OH.CH_2.COOH + HI$$

Other methods of synthesis which are suggested by its structure may be used.

The acid is a thick, sour liquid which cannot be distilled without decomposition. When heated alone, or in the presence of a dehydrating agent, it readily loses water and acrylic acid is formed:

$$CH_2OH.CH_2.COOH = CH_2:CH.COOH + H_2O$$

The acid derives its name from its relation to acrylic acid. Hydracrylic acid is converted on oxidation into malonic acid:

$$\begin{matrix} CH_2OH \\ | \\ CH_2COOH \end{matrix} + 2O = \begin{matrix} COOH \\ | \\ CH_2.COOH \end{matrix} + H_2O$$

This reaction, in which a carboxyl group is formed, is strong evidence that hydracrylic acid contains a primary alcoholic group.

317. Glyceric acid, $CH_2OH.CHOH.COOH$, is an example of a dihydroxy acid. Its name indicates its relation to glycerol from which it is prepared by careful oxidation:

$$CH_2OH.CHOH.CH_2OH + 2O = CH_2OH.CHOH.COOH + H_2O$$

The formation of the acid from α,β-dibromopropionic acid fu nishes evidence of its structure:

$$CH_2Br.CHBr.COOH + 2AgOH = CH_2OH.CHOH.COOH + 2AgBr$$

Glyceric acid is a thick, syrupy liquid, which is miscible all proportions with alcohol and with water. According to t structure assigned to it, the acid contains an asymmetric carb atom. Glyceric acid does not affect polarized light, but a sol tion of its ammonium salt is rendered optically active by *Pe cillium glaucum*. A thorough investigation of the subject woul no doubt, lead to results similar to those obtained in the ca of lactic acid.

318. Polyhydroxy-monocarboxylic Acids.—The polyhydro alcohols yield monocarboxylic acids on careful oxidation. Thu from erythritol $CH_2OH.CHOH.CHOH.CH_2OH$, erythric ac $CH_2OH.CHOH.CHOH.COOH$ is obtained. The pentahydro alcohols give tetrahydroxy-monocarboxylic acids. The aci derived from the hexahydroxy alcohols are of importance account of their relation to the sugars. It will be recalled that number of alcohols of the formula $CH_2OH(CHOH)_4CH_2OH$ exi As a molecule of this structure contains four asymmetric carb atoms the number of possible stereoisomers which have th formula is great. There are three mannonic acids correspondi to the *dextro*, the *levo*, and the *inactive* varieties of mannit There are acids isomeric with mannonic acid which bear a simil relation to the other hexahydroxy alcohols. Three *gluconic*, thr *gulonic*, and three *galactonic* acids are known. The constituti of all these acids is represented by the formula $CH_2OH(CHOH$ COOH.

Hydroxy Dicarboxylic Acids

319. Tartronic acid, $CHOH(COOH)_2$, can be prepared from malo acid, of which it is a hydroxyl derivative, by the general method used replace a hydrogen atom by a hydroxyl group. When malonic acid treated with bromine, bromomalonic acid is formed, which is convert into tartronic acid when boiled with silver oxide and water:

$$CH_2(COOH)_2 \xrightarrow{Br} CHBr(COOH)_2 \xrightarrow{AgOH} CHOH(COOH)_2$$

The acid crystallizes from water and melts at 158°.

320. Malic acid, $\begin{matrix}\text{CHOH.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{matrix}$, is a hydroxyl derivative of succinic acid. It was first described by Scheele in 1785, who called it malic acid, as he isolated it from unripe apples. The acid is widely distributed in the vegetable kingdom and plays an important part in the growth of plants. It occurs in apples, cherries, gooseberries, raspberries, strawberries, currants, and other acidulous fruits. It is also found in the roots of marshmallow and licorice; in the leaves and stems of hemp, lettuce, and tobacco; in the seeds of caraway, parsley, flax, and pepper; in carrots, potatoes, pineapples, and grapes; and in many other vegetable substances. The malic acid prepared from fruits is optically active.

Malic acid is *prepared industrially* by heating maleic acid (**143**) with water in the presence of a small amount of sulphuric acid. The reaction consists in the addition of a hydrogen atom and a hydroxyl group to the unsaturated carbon atoms.

Malic acid is a solid, which is very soluble in water and crystallizes with difficulty. It melts at 100°. It may be prepared in a number of ways, which are examples of the general methods already emphasized.

321. *The structure of malic acid* is deduced from its various syntheses and from its reactions. When heated with hydriodic acid, succinic acid is formed:

$$\begin{matrix}\text{CHOH.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{matrix} + 2\text{HI} = \begin{matrix}\text{CH}_2\text{.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{matrix} + \text{H}_2\text{O} + \text{I}_2$$

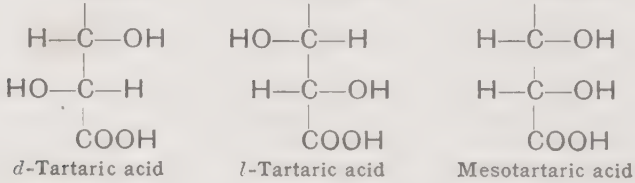
Hydrobromic acid converts malic acid into bromosuccinic acid:

$$\begin{matrix}\text{CHBr.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{matrix}$$

322. Dihydroxysuccinic Acids, $\begin{matrix}\text{CHOH.COOH}\\ |\\ \text{CHOH.COOH}\end{matrix}$.—Four dihydroxysuccinic acids of this formula are known; two are active and two are inactive. The compounds described up to this point that contain asymmetric carbon atoms exist in three forms, only one of which is inactive. The existence of a second inactive

form in the case of dihydroxysuccinic acid is readily explained This acid contains two asymmetric carbon atoms, and each ha an effect on the optical activity of the molecule. If the tw asymmetric groupings of the atoms turn the plane of polariza tion to the right, the acid is dextrorotatory; if to the left, th acid is levorotatory. A combination of these two forms pro duces an inactive variety. There is, however, another possibl arrangement. One of the asymmetric groupings in the molecul may be dextrorotatory and the other levorotatory. In thi case one part of the molecule neutralizes the effect of the othe and an inactive substance results.

The active forms of dihydroxysuccinic acid are named dextro tartaric acid and levotartaric acid. The former occurs widel distributed in nature, and is usually called "tartaric acid," th prefix being omitted. The inactive acid which is a mixture o dextro- and levo-tartaric acid, is racemic acid. The form whic is rendered inactive by internal compensation within the mole cule is mesotartaric acid or inactive tartaric acid. The relation indicated are illustrated by the following formulas which repre sent the stereochemical configuration of *d*-, *l*-, and mesotartari acids. Racemic acid is formed by mixing the two active forms:



d-Tartaric acid *l*-Tartaric acid Mesotartaric acid

There is a marked difference between the two inactive forms Racemic acid may be separated into *d*- and *l*-tartaric acid b the methods which have been described under *i*-lactic acid Mesotartaric acid, not being a mixture of different kinds o molecules, cannot be so separated. It is changed into th active form of tartaric acid only by the application of heat when the molecule undergoes decomposition and a new arrange ment of atoms is brought about.

The term *racemic* is used as a general term in describin stereoisomers to indicate that an inactive substance consist

either of a mixture of the dextro- and levo-rotatory forms or is produced as the result of the formation of a molecular compound from these forms (**328**). Thus, the acid which has been called inactive malic acid is said to be the racemic form of malic acid. The racemic form of an optically active compound is usually designated by placing before the name of the compound the letters *dl*; for example, inactive malic acid is *dl*-malic acid.

323. *d*-Tartaric acid is widely distributed in nature in the free condition and in the form of its potassium and calcium salts. It occurs abundantly in grapes as acid potassium tartrate, which is the source of the acid of commerce. Tartaric acid crystallizes in transparent monoclinic prisms, which are readily soluble in water; it melts at 170° and is dextrorotatory. When gently heated, the acid becomes electrified, the opposite ends of the crystals assuming opposite polarity. Above its melting point it first loses water and forms a number of different anhydrides. As the temperature is raised it turns brown, and a mass is produced which has the odor of burnt sugar. At a still higher temperature, charring takes place; from the product of decomposition pyroracemic (**336**) and pyrotartaric (methylsuccinic) acids have been isolated. When tartaric acid is boiled with water or hydrochloric acid, it is partly converted into racemic acid. When an aqueous solution of the acid is heated in a sealed tube at 175°, the conversion into racemic acid is almost complete.

The reactions and syntheses of tartaric acid lead to the structure which has been assigned to it. When heated with hydriodic acid it is reduced to malic and to succinic acids:

$$\begin{array}{l}\text{CHOH.COOH}\\ \text{CHOH.COOH}\end{array} \xrightarrow{\text{H}} \begin{array}{l}\text{CHOH.COOH}\\ \text{CH}_2\text{.COOH}\end{array} \xrightarrow{\text{H}} \begin{array}{l}\text{CH}_2\text{.COOH}\\ \text{CH}_2\text{.COOH}\end{array}$$

When tartaric acid is heated with alcohol in the presence of hydrogen chloride, two hydrogen atoms are replaced by two ethyl groups and diethyl tartrate is formed. This reaction shows that the acid contains two carboxyl groups. When diethyl tartrate is heated with acetic anhydride, two acetyl groups are introduced. The ester, therefore, contains two alcoholic hydroxyl groups.

When dibromosuccinic acid is heated with silver oxide an water, racemic acid is formed:

$$\begin{matrix}\mathrm{CHBr.COOH}\\ |\\ \mathrm{CHBr.COOH}\end{matrix} + 2\mathrm{AgOH} = \begin{matrix}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CHOH.COOH}\end{matrix} + 2\mathrm{AgBr}$$

d-Tartaric and *l*-tartaric acid can be obtained in a number ways from the acid thus synthesized.

324. The accumulation of negative groups in tartaric acid brings abo the development of weakly acidic properties in the alcoholic hydroxyl grou which it contains. Sodium hydroxide does not precipitate the hydroxides copper and of certain other metals in the presence of potassium or sodiu tartrate. A quantitative study of the reaction has shown that one mol ecule of sodium tartrate reacts with one molecule of copper hydroxide. Th structure of the salt formed is represented by the following formula:

$$\mathrm{Cu}\begin{matrix}\mathrm{O.CH.COONa}\\ |\\ \mathrm{O.CH.COONa}\end{matrix}$$

It has been obtained in the form of crystals, which contain two molecules water crystallization. The color of the solution formed by adding copp sulphate to an alkaline solution of sodium tartrate is deep blue; it resembl closely that produced when an excess of ammonia is added to a cupric sa When a solution of this blue salt of tartaric acid is subjected to electrolys the sodium travels to the cathode and the copper to the anode. The regi around the cathode loses its color and, finally, contains no copper, and th around the anode becomes richer in copper. These facts indicate that t copper is contained in the negative ion of the salt—a conclusion which in accord with the structure assigned to it. The solution formed by addi copper sulphate to an alkaline solution of a tartrate is called *Fehling's so tion.* It is a mild oxidizing agent, and is much used as a reagent in the stu of carbohydrates.

325. Tartaric acid and its salts have a number of commerci applications. The acid is used in dyeing and in one form baking powder. *Acid potassium tartrate*, $C_4H_4O_6.KH$, occurs many fruits. It is obtained commercially from *argol*, whi is the deposit formed in wine casks during the fermentation grape juice. The salt is but slightly soluble in water, and solubility is diminished in the presence of alcohol. As ferment tion proceeds it is precipitated, along with tannin, colori matters, and albuminous substances. The pure salt is obtain from the mixture by boiling it with water and bone black, a

evaporating the clear solution after filtering. Acid potassium tartrate is commonly called "cream of tartar."

326. Cream of tartar is used in large quantities in the manufacture of the so-called *tartrate baking powders*. These consist of a mixture of cream of tartar, sodium bicarbonate, and starch. When water is added to baking powder, the acid tartrate and bicarbonate react, and carbon dioxide is formed:

$$\begin{matrix}\text{CHOH.COOK}\\|\\\text{CHOH.COOH}\end{matrix} + \text{NaHCO}_3 = \begin{matrix}\text{CHOH.COOK}\\|\\\text{CHOH.COONa}\end{matrix} + \text{H}_2\text{O} + \text{CO}_2$$

Starch is added to baking powder for two reasons: it covers the particles of the salts present, and thus protects them from moisture and from interacting when the powder is stored, and it serves as a diluent. It is customary to make baking powders which liberate about 13 per cent of their weight of carbon dioxide when treated with water. As a mixture of equal molecular quantities of cream of tartar and sodium bicarbonate produces more than this amount of carbon dioxide, an inert substance must be added to reduce that formed to the percentage desired. Baking powders are also made by mixing sodium bicarbonate with primary calcium phosphate or with sodium and aluminium sulphates. The presence of a tartrate in a baking powder can be determined by applying the test for tartaric acid which is described below.

Rochelle salt is the name given to sodium potassium tartrate, $C_4H_4O_6KNa.4H_2O$. It can be obtained readily in pure condition, as it crystallizes well. It is used in the preparation of Fehling's solution, and in medicine as a diuretic and a purgative. "Seidlitz powders" contain (1) Rochelle salt and sodium bicarbonate and (2) tartaric acid. When solutions of the two powders are mixed there is a vigorous evolution of carbon dioxide.

Tartar emetic is the potassium antimonyl salt of tartaric acid:

$$\left[\begin{matrix}\text{CHOH.COOK}\\|\\\text{CHOH.COO(SbO)}\end{matrix}\right]_2.\text{H}_2\text{O}$$

It was formerly much used as an emetic, as it has an irritating effect on the alimentary canal which causes vomiting. It is used as a mordant in dyeing.

327. Tests for Tartaric Acid.—When a solution of calcium chloride is added to a neutral solution of a tartrate, calcium tartrate, $C_4H_4O_6Ca.4H_2O$, is precipitated. The latter is readily soluble in potassium hydroxide, but is precipitated in a gelatinous form on heating the solution to boiling. Ammonium salts should be excluded in making the test, as they interfere with the precipitation of calcium tartrate. A positive test for a tartrate should be confirmed by heating the substance with an

ammoniacal solution of silver nitrate, when, if a tartrate is present, the silver salt will be reduced and a mirror of the metal will be deposited. When tartaric acid or a tartrate is heated alone, the substance chars and an odor similar to that of burnt sugar is produced. When heated with concentrated sulphuric acid, carbon is deposited, and sulphur dioxide, carbon monoxide, and carbon dioxide are evolved.

328. Racemic acid occurs in nature free, or in the form of salts, along with tartaric acid and tartrates. Acid potassium racemate is much more soluble than acid potassium tartrate, and is obtained as a by-product in the preparation of the latter from argol. Racemic acid is formed when tartaric acid is heated with water or with solutions of hydrochloric acid or sodium hydroxide. It is a product of the oxidation of dulcitol, mannitol, cane sugar, and similar substances. It can be synthesized, along with mesotartaric acid, by heating a solution of dibromosuccinic acid with silver oxide. The acid and its salts differ markedly in physical properties from tartaric acid and the tartrates. Racemic acid melts at 206° and forms crystals which contain one molecule of water. Tartaric acid melts at 168° to 170° and is anhydrous.

329. Separation of Optical Isomers.—Racemic acid is of considerable historical interest as it was the first inactive substance to be resolved into optically active compounds. The remarkable discovery was made by Pasteur in 1848 in an investigation of the crystalline structure of the salts of racemic acid. It was found that two kinds of crystals, which differed slightly in the relative position of the faces they contained, were formed when a solution of the sodium ammonium salt of racemic acid was allowed to crystallize spontaneously. The relation in form which the two kinds of crystals bear to each other, is that of an object and its reflection in a mirror. Pasteur separated the two kinds of crystals and examined the solutions of each in polarized light. He found that one solution was dextrorotatory and the other was levorotatory. From the two salts two acids were isolated; one was ordinary *d*-tartaric acid, the other a new acid which was levorotatory. When equal weights of the two acids were mixed and recrystallized, inactive racemic acid was obtained.

It was shown later that if the crystals of sodium ammonium racemate are deposited from solution at a temperature above 28°, crystals of but one kind are obtained. These differ in form and content of water of crystallization from the crystals of the corresponding salts of *d*-tartaric and *l*-tartaric acids, which are obtained when the temperature is below 28°.

It is evident from the above and the fact that racemic acid melts at a higher temperature than the *d*- or *l*-tartaric acids that racemic acid in the solid form and its salts are not simple mixtures of the dextro and levo forms. They are, in all probability, molecular compounds which resemble the double salts that are readily decomposed into their constituents. Such decomposition takes place in the case of racemic acid when it is dissolved in water, for under these circumstances the molecular weight corresponds to that of the single molecule; the esters of the acid, when vaporized, are also monomolecular.

Pasteur devised in his investigation other important methods of breaking down the racemic form of acids into their optical isomers. He showed that the salts of the latter with optically active bases possess different solubilities and that this fact could be utilized in separating these acids into their constituents.

The third method devised by Pasteur depends on the action of certain moulds and bacteria on racemic compounds. One of the active substances is more rapidly destroyed than the other. When the mould *Penicillium glaucum* develops in a dilute solution of racemic acid, the dextrorotatory acid is destroyed and *l*-tartaric acid is obtained.

330. *l*-Tartaric acid can be prepared from racemic acid by the methods which have been mentioned in the last section. The acid has the same physical properties as tartaric acid except its action on polarized light. The extent to which the plane of polarization is rotated is the same in both cases, but the direction of rotation is different. The salts of the two acids are, in general, alike in solubility, content of water of crystallization, and so forth. It will be recalled, however, that there is a slight difference in the form of the crystals of sodium ammonium salts of *d*- and *l*-tartaric acid, and that the difference furnishes a method of separating these optical isomers.

331. Mesotartaric acid is formed along with racemic acid when tartaric acid is heated with water at 165° for two days, or when a solution of sodium tartrate is boiled for a number of hours with sodium hydroxide. It can be synthesized by heating dibromosuccinic acid with silver oxide and water, racemic acid being formed at the same time. Mesotartaric acid differs in physical properties from tartaric acid and racemic acid. It crystallizes with one molecule of water of crystallization. The anhydrous acid melts at 140°. The stereochemical relations of mesotartaric acid have already been explained (**322**).

332. Citric acid, $\begin{matrix}CH_2COOH\\|\\C(OH)COOH.H_2O,\\|\\CH_2COOH\end{matrix}$ is a monohydroxy-tricarboxylic acid. The fact that it contains three carboxyl groups and one alcoholic hydroxyl group is inferred from its chemical behavior. Citric acid, like other tribasic acids, forms three potassium salts. The composition of its ethyl ester also indicates that the acid is tribasic. When the ester is treated with acetic anhydride, one hydrogen atom is replaced by an acetyl group. This reaction shows that the substance contains one alcoholic hydroxyl group. The position of this group is determined by a synthesis of citric acid from acetone-dicarboxylic acid, which is, as implied in the name, acetone in which two hydrogen atoms are replaced by two carboxyl groups. The steps in the synthesis of citric acid are represented by the following formulas:

$$\begin{matrix}CH_2COOH\\|\\C{=}O\\|\\CH_2COOH\end{matrix} \xrightarrow{HCN} \begin{matrix}CH_2COOH\\|\\C(OH)\\|\\CN\\|\\CH_2COOH\end{matrix} \xrightarrow{HOH} \begin{matrix}CH_2COOH\\|\\C(OH)\\|\\COOH\\|\\CH_2COOH\end{matrix}$$

Citric acid occurs widely distributed in nature in many fruits. It is present in raspberries, gooseberries, currants, and other acidulous fruits. It is usually obtained from unripe lemons, the juice of which contains about 6 per cent of the free acid. In isolating the acid, the juice is neutralized at the ordinary temperature with calcium carbonate and filtered. Tricalcium citrate dissolves readily in cold water, but is difficultly soluble in hot water. As a consequence, when the solution of the citrate

obtained from the lemon juice is boiled, the calcium salt of the acid precipitates. This is separated and treated with an equivalent quantity of sulphuric acid; after the removal of calcium sulphate, citric acid is obtained by evaporation of the solution to crystallization. Citric acid is formed as the result of the fermentation of glucose by *Citromycetes pfefferianus*. It is prepared on a technical scale in this way.

Citric acid crystallizes from water in rhombic prisms, which melt at 100° and contain one molecule of water of crystallization. The hydrated acid loses water at about 130°. The anhydrous acid melts at 153°.

Citric acid is used in the manufacture of lemonade and in calico printing. A number of its salts have important applications.

Magnesium citrate, $(C_6H_5O_7)_2Mg_3.14H_2O$, is used in medicine. *Ferric ammonium citrate*, $(C_6H_5O_7Fe.C_6H_5O_7(NH_4)_2H)$, is used in making blue-print paper (**246**). A strong solution of neutral ammonium citrate is used in the analysis of fertilizers in the separation of the different forms of phosphates which the fertilizers contain.

333. Saccharic acid and mucic acid, $\begin{matrix}COOH\\|\\(CHOH)_4\\|\\COOH\end{matrix}$, are the more important of a large number of acids which have been shown to have this formula. As the configuration represented by this formula contains four asymmetric carbon atoms, 16 stereoisomers are possible. The number of such isomers is 2^n, where n is the number of asymmetric carbon atoms in the molecule. *d*-Saccharic acid is formed as the result of the oxidation of glucose, cane sugar, and milk sugar, by nitric acid. As the last two are converted into glucose by hydrolysis, *d*-saccharic acid is probably formed as the first oxidation product of glucose. The reaction is readily understood. It will be shown later that glucose contains a primary alcohol group and an aldehyde group. In the change to saccharic acid these groups are converted into carboxyl:

$$\begin{matrix}CH_2OH\\|\\(CHOH)_4\\|\\CHO\end{matrix} \xrightarrow{3O} \begin{matrix}COOH\\|\\(CHOH)_4\\|\\COOH\end{matrix} + H_2O$$

The constitution of saccharic acid is inferred from its relation to glucose, and from the fact that it is reduced by hydriodic acid to adipic acid:

$$\begin{matrix}\mathrm{COOH}\\|\\(\mathrm{CHOH})_4\\|\\\mathrm{COOH}\end{matrix} + 8\mathrm{HI} = \begin{matrix}\mathrm{COOH}\\|\\(\mathrm{CH_2})_4\\|\\\mathrm{COOH}\end{matrix} + 4\mathrm{H_2O} + 4\mathrm{I_2}$$

Saccharic acid is used in connection with potassium dichromate in mordanting cloth. It forms a well-characterized acid potassium salt which is precipitated when a strong solution of the acid is treated with potassium acetate; the reaction is now being used in connection with the identification of glucose.

Mucic acid is formed by the oxidation of galactose and of other substances which give this sugar on hydrolysis. As galactose is a stereoisomer of glucose, and as hydriodic acid reduces mucic acid to adipic acid, it is inferred that mucic acid is a stereoisomer of saccharic acid. The acid is best prepared by oxidizing sugar of milk with nitric acid. It is optically inactive, and cannot be resolved into optically active compounds. Mucic acid is sparingly soluble in water; its formation when a carbohydrate is oxidized with nitric acid is used as a test for galactose or a compound which yields this compound on hydrolysis.

Aldehyde Acids and Ketone Acids

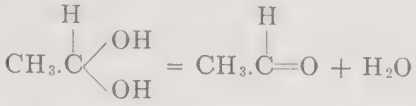
334. Glyoxylic acid, $\begin{matrix}\mathrm{CHO}\\|\\\mathrm{COOH}\end{matrix}.\mathrm{H_2O}$, is the simplest example of compounds which contain the groups characteristic of aldehydes and of acids. It is found in the leaves and the unripe fruits of many plants. It can be prepared by heating dibromoacetic acid with water for 24 hours in a sealed tube at 135°

$$\mathrm{CHBr_2.COOH} + \mathrm{HOH} = \mathrm{CHO.COOH} + 2\mathrm{HBr}$$

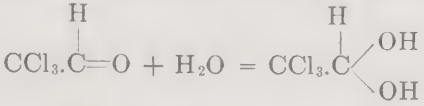
or by the partial oxidation of alcohol by nitric acid.

335. The acid is a crystalline substance, very soluble in water, and has the composition $\mathrm{CHO.COOH.H_2O}$. The added water does not appear to be "water of crystallization." When an attempt is made to drive the water out of the compound, complete decomposition results. For this reason the structure sometimes assigned to glyoxylic acid is that represented by the formula $\begin{matrix}\mathrm{HO}\\\\\mathrm{HO}\end{matrix}\!\!\rangle\mathrm{CH.COOH}$. If this view of the structure is correct, the compound is an exception to the general rule which has been given,—namely, that two hydroxyl groups cannot be held in combination by a single carbon

atom. Exceptions to this general statement are known. A consideration of the structure of compounds which contain two hydroxyl groups linked to a single carbon atom, brings out the fact that in all such compounds the carbon atom which shows this unusual power, is linked to a second carbon atom to which are united strongly negative atoms or groups. For example, whereas aldehyde is formed as the result of the elimination of water from a dihydroxyl derivative according to the equation



trichloroaldehyde adds water, and in all probability forms a compound which contains two hydroxyl groups joined to the same carbon atom:



Glyoxylic acid reduces an ammoniacal solution of silver nitrate, forms addition products with sodium hydrogen sulphite and ammonia, and gives an oxime with hydroxylamine. These reactions, which are all characteristic of aldehydes, lead to the view that the acid contains an aldehyde group; its structure is therefore best represented by the formula $CHO.COOH.H_2O$.

It is probable that in aqueous solution aldehyde and its derivatives exist in two forms which are in equilibrium:

$$R.CHO + H_2O \rightleftharpoons R.C(OH)_2$$

When such a solution is brought into contact with a reagent that reacts with the true aldehyde form, a reaction takes place; and as this form disappears, more of it is produced as a result of the shift in equilibrium; the reaction proceeds in this way until all of the form which contains two hydroxyl groups disappears. Many such reactions are known in organic as well as in inorganic chemistry.

336. Pyroracemic acid, $CH_3CO.COOH$, is an example of a compound which is both an acid and a ketone. The name was given to the acid when it was first prepared by heating racemic acid. The prefix *pyro* appears in the name of many substances, such as pyrophosphoric acid, pyrotartaric acid, pyrogallic acid, etc. It is derived from the Greek word meaning "fire," and was used in naming compounds to indicate that they were formed by the action of heat. Pyrogallic acid, for example, is formed when gallic acid is heated.

Pyroracemic acid, which is called also *pyruvic acid*, may be prepared by methods which furnish evidence in favor of the

structure assigned to it. It is formed, for example, by oxidizing lactic acid:

$$CH_3.CHOH.COOH + O = CH_3.CO.COOH + H_2O$$

In this case the reaction is normal—a secondary alcohol group is converted into the carbonyl (CO) group, which is present in ketones. It is also formed by the reactions indicated by the following equations:

$$CH_3.CCl_2.COOH + H_2O = CH_3.CO.COOH + 2HCl$$
$$CH_3CO.Cl + KCN = CH_3CO.CN + KCl$$
$$CH_3CO.CN + 2H_2O = CH_3CO.COOH + NH_3$$

Pyroracemic acid melts at 13.6° and boils at 165°. It shows the reactions of both acids and ketones. It forms salts, esters, an oxime, and an addition product with hydrocyanic acid. When heated with dilute sulphuric acid at 150°, it decomposes according to the following equation:

$$CH_3CO.COOH = CH_3.CHO + CO_2$$

337. Acetoacetic acid, $CH_3CO.CH_2COOH$, is so-called because it may be considered as acetic acid in which one hydrogen atom is replaced by the acetyl group. It is known only in solution, for when an attempt is made to isolate it, decomposition takes place. It is found in the urine of persons suffering from diabetes. It is often called in medicine *diacetic acid.*

338. Acetoacetic Ester: Tautomerism.—The ethyl ester of acetoacetic acid is of interest, as its study has led to a deeper insight into the nature of molecules and to a broadening of the theories of structural organic chemistry. Acetoacetic ester is also of importance from the practical point of view; by the use of appropriate reagents many compounds can be prepared from it by what is called the acetoacetic ester synthesis (Sec. **343**).

Preparation.—Acetoacetic ester is prepared by condensing ethyl acetate by means of sodium ethylate. Ethyl acetate containing a trace of ethyl alcohol is boiled with sodium. When the metal has dissolved, the reaction product is treated with dilute acid, and the oil set free is dried and purified by distillation. The various steps involved in the transformation of ethyl acetate into ethyl acetoacetate have been the subject of much discussion.

The view accepted by most chemists is that given by Claisen. It is as follows: When sodium is added to ethyl acetate it first reacts with the small amount of alcohol present to form sodium ethylate and hydrogen. The addition product of sodium ethylate and ethyl acetate which results, condenses with a second molecule of ethyl acetate:

$$CH_3.C(=O)OC_2H_5 + NaOC_2H_5 = CH_3.C(ONa)(OC_2H_5)OC_2H_5$$

$$CH_3.C(ONa)(OC_2H_5)OC_2H_5 + H.CH(H).C.COOC_2H_5 =$$

$$CH_3.C(ONa)=C(H).COOC_2H_5 + 2C_2H_5OH$$

The alcohol eliminated in the second reaction is converted by the metal into sodium ethylate, which serves to bring about the condensation of more ethyl acetate. Ethyl acetoacetate is liberated when the sodium compound is treated with an acid:

$$CH_3C(ONa):CH.COOC_2H_5 + CH_3COOH =$$
$$CH_3C(OH):CH.COOC_2H_5 + CH_3COONa$$

339. Structure.—This explanation of the formation of ethyl acetoacetate leads to the view that it is the ester of an unsaturated hydroxy acid. Some of its reactions are in accord with this view of its structure. On the other hand, it behaves with certain reagents as if it contained the group characteristic of ketones, and consequently its structure should be represented by the formula $CH_3CO.CH_2.COOC_2H_5$. A detailed study of the ester has led to the conclusion that it can exist in two forms and that the structure of these two forms can best be represented by the formulas which have been given. It has been shown, also, that one form of the ester can change spontaneously into the other form, and that the free ester is a mixture in which the two forms are in equilibrium:

$$CH_3C(OH):CH.COOC_2H_5 \rightleftharpoons CH_3CO.CH_2COOC_2H_5$$

The derivatives of acetoacetic ester are mixtures of substitution products of the two forms of the ester. The relation between the amounts of each form present in any substance varies with

the nature of the groups present in the molecule; in some, the form which contains the ketone group largely predominates, while in others the unsaturated compound is present in the larger quantity. The form which contains the hydroxyl group is designated by the word *enol;* that which contains the carbonyl group is the *keto* form.

340. Tautomerism.—This explanation of the structure of acetoacetic ester and its derivatives makes it necessary to recognize a kind of isomerism unlike that in the case of the two dibromoethanes, $CH_3.CHBr_2$ and $CH_2Br.CH_2Br$. The latter are stable compounds under ordinary conditions, whereas the isomeric forms of acetoacetic ester change spontaneously one into the other. Isomerism of the latter type is called *tautomerism.* When the two tautomeric forms can be isolated, the phenomenon is known as *desmotropy.* The *keto* form of acetoacetic ester crystallizes from ether at $-78°$ in needles, which melt at $-39°$. The *enol* form, which is obtained by treating the sodium salt of the ester with an ethereal solution of hydrogen chloride, is an oil that does not solidify at $-78°$; it changes slowly into the *keto* form until an equilibrium between the two modifications is reached. About two weeks are required for this change to take place at room temperature. The rearrangement of the *keto* to the *enol* variety takes place much more slowly. The equilibrium mixture contains about 7 per cent of the *enol* and 93 per cent of the *keto* form; it boils at 180°.

341. *Rearrangement of Tautomers.*—A number of experimental methods have been discovered of following the rearrangement of one form of a tautomeric compound into the other. It has been found that a colored substance is formed when a compound which has the *enol* structure is treated with ferric chloride; the *keto* form is not affected by this reagent. If ferric chloride is added to a comparatively stable substance which has the *keto* structure no color appears; as the transformation progresses a color develops and increases in intensity until equilibrium is established. If the reagent is added to the *enol* form of the same substance, the color appears at once; it decreases in intensity as the rearrangement to the *keto* form takes place, until the equilibrium point is reached.

A second method of investigating the structure of tautomeric compounds is that devised by Brühl, who showed that substances which contain carbon atoms linked by a double bond disperse and refract light more strongly than saturated compounds. As the *enol* form of tautomers contains doubly linked carbon atoms, and the *keto* form does not, the rearrangement of one

form into the other can be followed by examining the optical properties of the substances studied.

In the case of desmotropic compounds or of tautomers that rearrange slowly, a method worked out by Kurt Meyer can be used advantageously. This is based upon the fact that the *enol* form, like other compounds which contain two carbon atoms linked by a double bond, unites directly with bromine; the *keto* form does not add the halogen. The determination of the amount of the *enol* form is carried out by adding an excess of bromine, destroying the excess, and then treating the dibromo addition product with potassium iodide; iodine equivalent to the bromine added is set free and can be determined by titration.

These methods of investigating the change of tautomers, one into the other, has led to the discovery that the rate at which the change takes place is affected by the temperature and the nature of the liquid in which the compound is dissolved. Increase in temperature and solvents containing the hydroxyl group, such as water and alcohol, increase the rate of change. When the solvent used is a hydrocarbon or halogen derivative, the rate is greatly reduced. The proportion of the two forms present at equilibrium also varies markedly with the solvent. In the case of acetoacetic ester 12 per cent of the *enol* form is present in the equilibrium mixture when the solvent is ethyl alcohol; in other solvents the percentages are as follows: water 0.4, methyl alcohol 6.9, amyl alcohol 15.3, ether 27.1, hexane 46.4.

342. Chemical Properties of Acetoacetic Ester.—The chemical properties of acetoacetic ester are those of a ketone and an ester. It contains, however, a small proportion of the tautomeric *enol* form of the compound, as a color is produced when it is treated with ferric chloride. The ester dissolves in alkalies owing to the formation of a soluble sodium salt. It is believed that the salt is formed as the result of the interaction of the alkali with that part of the ester which has the *enol* structure. As the latter is removed in this way the *keto* form undergoes rearrangement to the *enol* form in order to establish the normal equilibrium between the two forms. The change continues until, in the end, the ester dissolves completely. When an aqueous solution of the sodium salt of acetoacetic ester is treated with an acid, the *enol* form of the ester is first precipitated in drops; these slowly disappear as a result of their transformation into the *keto* form provided enough water is present. The solubility of the *enol* form in water is much less than that of the *keto* form (0.5 and 11 per cent, respectively, at 0°).

343. Acetoacetic Ester Synthesis.—The hydrolysis of acetoacetic ester and its derivatives presents many points of interest,

on account of the fact that the acid and its substitution products, which are formed by the hydrolysis, are unstable and yield important decomposition products.

When the saponification of acetoacetic ester is effected by boiling it with a dilute aqueous solution of an acid or a base, it is probable that alcohol and acetoacetic acid are first formed:

$$CH_3CO.CH_2COOC_2H_5 + HOH = CH_3CO.CH_2COOH + C_2H_5OH$$

The acid is, however, unstable under these conditions, and decomposes, yielding acetone and carbon dioxide:

$$CH_3.CO.CH_2.COOH = CH_3.CO.CH_3 + CO_2$$

When acetoacetic ester is hydrolyzed by boiling it with a strong aqueous solution of an alkali, or with an alcoholic solution of sodium hydroxide, the sodium salt of acetoacetic ester, $CH_3C(ONa):CH.COOC_2H_5$, which is first formed, is hydrolyzed in all probability according to the equation:

$$CH_3C(ONa):CH.COOC_2H_5 + NaOH = CH_3C(ONa):CH.COONa + C_2H_5OH$$

In the presence of the strong alkali, the salt undergoes decomposition as the result of the addition of water at the double bond, and two molecules of sodium acetate are formed:

$$CH_3.\underset{\underset{ONa}{|}}{C}:CH.COONa + H_2O = CH_3.\underset{\underset{ONa}{|}}{CO} + CH_3COONa$$

The derivatives of acetoacetic ester undergo decompositions similar to those of the ester itself. As many substitution products of acetoacetic ester can be prepared, we have, thus, a means of synthesizing substitution products of acetone and of acetic acid.

When the sodium derivative of acetoacetic ester is warmed with an alkyl halide, the metallic atom is replaced by an alkyl group. The stable form of these substances appears to have the *keto* structure. The reaction is usually effected by treating an alcoholic solution of acetoacetic ester with the calculated quantity of sodium ethylate, which converts the ester into its sodium derivative:

$$CH_3CO.CH_2COOC_2H_5 + C_2H_5ONa = CH_3C(ONa):CHCOOC_2H_5 + C_2H_5OH$$

The alkyl iodide is then added and the solution boiled until the reaction is complete:

$$CH_3.C(ONa):CHCOOC_2H_5 + CH_3I = CH_3.CO.CH(CH_3).COOC_2H_5 + NaI$$

The resulting compound is now hydrolyzed by either of the methods which have been described. *When the ester is boiled with a dilute solution of an acid or an alkali, the decomposition yields,* in the example given, *methyl ethyl ketone* and *carbon dioxide:*

$$CH_3.CO.CH(CH_3).COOH = CH_3.CO.CH_2CH_3 + CO_2$$

This is an example of what is known as the *ketonic hydrolysis.*

When the ester is hydrolyzed by boiling with an alcoholic solution of an alkali, the salts of two acids, which in this case are acetic acid and propionic acid, *are formed.* This is known as the *acid hydrolysis:*

$$CH_3.CO.CH(CH_3).COOH + HOH = CH_3.COOH + CH_3CH_2.COOH$$

It is evident that by varying the alkyl halide used in the synthesis, a large number of ketones and acids may be prepared.

The alkyl substitution products of acetoacetic ester, which can be prepared by the methods just described, react with sodium ethylate and form metallic derivatives:

$$CH_3.CO.CH(CH_3).COOC_2H_5 + C_2H_5ONa = CH_3.C(ONa):C(CH_3).COOC_2H_5 + C_2H_5OH$$

These, in turn, react with alkyl halides and yield substitution products of acetoacetic ester which contain two alkyl radicals:

$$CH_3.C(ONa):C(CH_3).COOC_2H_5 + C_2H_5I = CH_3.CO.C(CH_3)(C_2H_5).COOC_2H_5 + NaI$$

Ketonic hydrolysis of this compound yields methyl sec.-butyl ketone:

$$CH_3.CO.C(CH_3)(C_2H_5).COOH = CH_3.CO.CH\begin{matrix}CH_3\\C_2H_5\end{matrix} + CO_2$$

Acid hydrolysis yields acetic acid and a valeric acid:

$$CH_3.CO.C(CH_3)(C_2H_5).COOH + HOH = CH_3.COOH + \begin{matrix}C_2H_5\\CH_3\end{matrix}\!\!>\!CH.COOH$$

It will be seen from the examples given that by means of the acetoacetic ester synthesis ketones of the structure $CH_3.CO.CH_2R$ and $CH_3.CO.CHRR'$ may be prepared. R and R' indicate radicals. Acid hydrolysis yields acids of the structure $RCH_2.COOH$ and $RR'CH.COOH$.

Acyl chlorides, as well as alkyl halides, react with the sodium derivative of acetoacetic ester; as a consequence, ketones and acids which contain acyl radicals can be prepared by means of this synthesis.

Halogen Substitution Products of Alcohols, Aldehydes, and Ketones

344. Many halogen substitution products of the various classes of compounds, which have been described, are known. Some of these are of special interest as they illustrate in their methods of preparation and reactions important principles of organic chemistry. It would lead too far to describe many of these compounds or others of a more complex structure, such as those which contain three or more characteristic groups in the molecule. A few typical compounds only will be mentioned.

345. Halogen Derivatives of Alcohols.—Substitution products of alcohols cannot be prepared as a rule by the action of the halogens on the alcohols. Derivatives of an aldehyde are formed when a saturated alcohol is treated, for example, with chlorine. Halogen derivatives of the alcohols must accordingly be made by indirect methods. They are formed (1) by the action of hypochlorous acid on unsaturated hydrocarbons:

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + \begin{matrix} OH \\ | \\ Cl \end{matrix} = \begin{matrix} CH_2OH \\ | \\ CH_2Cl \end{matrix}$$

(2) by the partial hydrolysis of dihalogen derivatives:

$$\begin{matrix} CH_2Br \\ | \\ CH_2Br \end{matrix} + H_2O = \begin{matrix} CH_2Br \\ | \\ CHOH \end{matrix} + HBr$$

(3) by the action of the halogens on unsaturated alcohols:

$$CH_2:CH.CH_2OH + Cl_2 = CH_2Cl.CHCl.CH_2OH$$

and (4) by the action of the hydrogen halides on polyhydroxy alcohols:

$$CH_2OH.CHOH.CH_2OH + 2HCl = CH_2Cl.CHOH.CH_2Cl + 2H_2O$$

In the last case, the conditions under which the reaction is brought about determine the extent to which the hydroxyl groups are replaced by halogen. For example, when glycerol is heated with dry hydrogen chloride, the chief product of the reaction has the structure $CH_2Cl.CHOH.CH_2OH$. When the reaction takes place in a glacial acetic acid solution, two hydroxyl groups are replaced by chlorine atoms.

The chemical properties of the halogen substitution products of the alcohol are, in general, those shown by alcohols and those shown by the alkyl halides. The presence of the negative halogen atom in the alcohol modifies to some extent the reactivity of the hydroxyl group, and likewise the presence of the latter affects the ease with which the halogen enters into reaction with other substances. For example, the halogen atom in ethylene chlorohydrin, $CH_2Cl.CH_2OH$, is much more readily replaced by hydroxyl than is the chlorine atom in ethyl chloride; and the hydroxyl group in the chlorohydrin is more reactive than that in ethyl alcohol.

346. Halogen Derivatives of Ethers.—A number of halogen derivatives of ethyl ether are known, which can be prepared by the action of chlorine on the ether.

It is of interest to note the difference in the rate of hydrolysis of the two isomers of the structures indicated by the formulas $CH_2ClCH_2OCH_2CH_3$ and $CH_3CHClOCH_2CH_3$. The first, β-chloroether, is stable toward water, whereas the second is rapidly hydrolyzed in the presence of acids. The reaction in this case resembles the hydrolysis of an ester—the bond between oxygen and carbon is broken as the result of the addition of water

$$CH_3CHClOC_2H_5 + HOH = CH_3CHClOH + HOC_2H_5$$
$$CH_3COOC_2H_5 + HOH = CH_3COOH + HOC_2H_5$$

The compound formed from the ether immediately decomposes as we might expect, since it contains a carbon atom linked to chlorine and hydroxyl:

$$CH_3CH\begin{matrix}Cl\\OH\end{matrix} = CH_3CHO + HCl$$

In this case we have an ether that reacts with water as an ester does. The reaction is brought about as the result of the fact that the replacement of an α-hydrogen atom in the ethyl group by a negative chlorine atom renders the bond between this group and oxygen more reactive to water. The relationship, from this point of view, between the chloroether and ethyl acetate is shown by the following formulas:

Many such cases are known among organic compounds. In general, *the accumulation of negative elements around a carbon atom results in rendering the compound more reactive at this carbon atom.*

347. Halogen Derivatives of Aldehydes.—The most important of these compounds is trichloroaldehyde, $CCl_3.CHO$, which is usually called "chloral." It is formed when an aqueous solution of aldehyde is treated with chlorine, but is usually prepared by the action of the halogen on anhydrous alcohol. The reactions involved are complicated. It has already been pointed out that chlorine converts alcohol into aldehyde. A reaction may be written for the change:

$$CH_3.CH_2OH + Cl_2 = CH_3.CHO + 2HCl$$

The aldehyde reacts with chlorine and is converted into trichloroaldehyde, which in turn unites with water set free in a secondary reaction to form chloral hydrate. The changes are indicated by the formulas:

$$CH_3.CHO \xrightarrow{Cl_2} CCl_3.CHO \xrightarrow{H_2O} CCl_3.CHO.H_2O$$

348. The fact that hydrogen chloride is formed as the result of the substitution of hydrogen by chlorine, leads to reactions other than substitution. It will be recalled that aldehydes undergo condensation with alcohols and form acetals in the presence of hydrogen chloride, which catalyzes the reaction (**187**):

$$CH_3CHO + \begin{matrix} HOC_2H_5 \\ HOC_2H_5 \end{matrix} = CH_3CH\begin{matrix} OC_2H_5 \\ OC_2H_5 \end{matrix} + H_2O$$

When chlorine is passed into alcohol the conditions are favorable for this reaction and acetal is formed. The latter then is converted into trichloroacetal:

$$CH_3.CH(OC_2H_5)_2 + 3Cl_2 = CCl_3.CH(OC_2H_5)_2 + 3HCl$$

In the presence of the acid some of the acetal is decomposed:

$$CCl_3.CH\begin{matrix}OC_2H_5\\OC_2H_5\end{matrix} + HCl = CCl_3.CH\begin{matrix}OH\\OC_2H_5\end{matrix} + C_2H_5Cl$$

The resulting product is called chloral alcoholate, as it can be formed by the direct union of chloral and alcohol. As the consequence of all these reactions, the product finally obtained when alcohol is treated with chlorine is a mixture which contains chloral hydrate, trichloroacetal, and chloral alcoholate. Chloral is set free from these compounds when the mixture is treated with concentrated sulphuric acid.

349. *Chloral* is an oily liquid, which has a penetrating odor; it boils at 98.1° and has the specific gravity 1.512 at $\frac{20°}{4°}$. It reacts with water with the evolution of heat, and forms chloral hydrate, a compound which crystallizes well from water and melts at 47.4°. Chloral hydrate is much used as a soporific. The formula usually assigned to chloral hydrate is $CCl_3.CH(OH)_2$. Chloral hydrate shows most of the reactions of aldehydes: it reduces an ammoniacal solution of silver nitrate and reacts with hydroxylamine. It does not, however, affect Schiff's reagent (**191**). Concentrated sulphuric acid converts it into chloral.

Both chloral and chloral hydrate yield trichloroacetic acid when oxidized by concentrated nitric acid, the reaction which takes place being that characteristic of aldehydes. When treated with a solution of potassium hydroxide, chloral is decomposed in the cold, and chloroform is formed:

$$CCl_3\overset{H}{\underset{H}{\dot{C}}}:O\overset{}{\underset{OK}{}} = CCl_3H + HCOOK$$

This decomposition is a further example of a principle which has been emphasized, namely, that the accumulation of negative atoms in a molecule markedly affects the union between the carbon atoms with which the negative atoms are in combination.

350. Halogen Derivatives of Ketones.—Compounds of this class are prepared by the action of chlorine and bromine on ketones, the substitution taking place readily. It has been

pointed out that the introduction of oxygen into a compound is facilitated, in general, by the presence of oxygen in the compound; alcohols, aldehydes, and ketones are much more readily oxidized than hydrocarbons. The presence of the negative atom, in some way, makes it easier to introduce a second negative atom. This is true not only in the case where the latter is oxygen, but where it is another negative atom. *Chlorine and bromine react much more readily with the oxygen derivatives of the hydrocarbons than with the hydrocarbons themselves.*

A number of substitution products of acetone can be formed by the action of chlorine on acetone. The extent to which substitution takes place is determined by such conditions as the relation between the amounts of substances used, the temperature, the presence of catalytic agents, etc. The dichloroacetone formed by direct substitution has the structure $CHCl_2.CO.CH_3$. The isomeric compound of the structure $CH_2Cl.CO.CH_2Cl$ cannot be prepared from acetone. It is prepared from glycerol by the steps indicated by the following formulas:

$$CH_2OH.CHOH.CH_2OH \xrightarrow{HCl} CH_2Cl.CHOH.CH_2Cl \xrightarrow{O} CH_2Cl.CO.CH_2Cl$$

These facts in regard to the dichloroacetones have been mentioned as an illustration of an important principle in organic chemistry. In most cases all the possible substitution products of a compound are not formed as the result of the direct introduction of the substituent into the compound. The position taken by the entering atom is determined by the configuration of the molecule and the nature of the atoms which it contains. When it is desired to prepare a derivative of a compound which is not formed by direct substitution, indirect methods must be resorted to. The method used in the preparation of the symmetrical dichloroacetone is an example. Another example is furnished by the β-halogen derivatives of propionic acid, which are prepared indirectly from glycerol.

The accumulation of halogen atoms in ketones brings about a change in chemical properties similar to that observed in the analogous derivatives of aldehydes. Hexachloroacetone, for example, forms a hydrate with water, $(CCl_3)_2CO.H_2O$, and, like other highly substituted derivatives of acetone, is decomposed

by alkalies. It is probable that the formation of chloroform from acetone and bleaching powder is the result of the decomposition of trichloroacetone, which appears to be an intermediate product in the reaction:

$$CH_3.CO.CH_3 \xrightarrow{Cl_2} CCl_3.CO.CH_3 \xrightarrow{Ca(OH)_2} CCl_3H + (CH_3COO)_2Ca$$

Acetone is likewise converted into bromoform, $CHBr_3$, when it is treated in aqueous solution with sodium hydroxide and bromine. Iodoform, CHI_3, is formed in a similar way.

Amino Acids

351. A great many compounds are known which contain two or more characteristic groups, one of which owes its properties to the presence of nitrogen. Only the amino acids and certain of their derivatives will be discussed here. The simplest member of this class is aminoformic acid, $NH_2.COOH$, which is usually called carbamic acid (**230**). Only the salts of the acid and its esters, which are called *urethans*, are known. Aminoacetic acid, $NH_2.CH_2COOH$, is a typical member of the series of amino acids. The formula assigned to it indicates that the acid is derived from acetic acid by the replacement of a hydrogen atom in the methyl group by an amino group, or from methylamine by the replacement of hydrogen by the carboxyl group. The reactions of the acid are in accord with this view of its structure.

352. Preparation of Amino Acids.—Amino acids may be prepared by the action of ammonia on halogen derivatives of the acids. The reaction is analogous to that by which amines are formed:

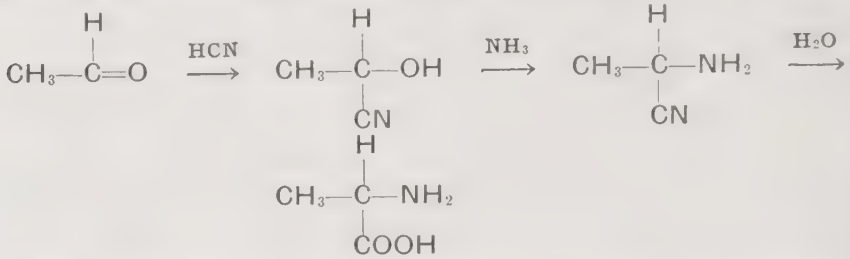
$$NH_3 + ClCH_2COOH = NH_2CH_2COOH + HCl$$

$$NH_3 + ClCH_3 = NH_2CH_3 + HCl$$

In both cases the compounds are obtained as salts, from which the acid or amine can be liberated by a base. When derivatives of ammonia are used, substitution products of the amino acids are formed:

$$CH_3NH_2 + ClCH_2COOH = CH_3NH.CH_2COOH + HCl$$

Another method of preparation which has been frequently used to synthesize the amino acids obtained from certain natural sources, is illustrated by the following formulas:



353. Reactions of Amino Acids.—The amino acids form salts with acids and with bases. The amino group present in these acids takes part in reactions characteristic of amines. When treated with nitrous acid, the amino acids are converted into hydroxy acids:

$$NH_2CH_2COOH + HNO_2 = HOCH_2COOH + N_2 + H_2O$$
$$NH_2CH_3 + HNO_2 = HOCH_3 + N_2 + H_2O$$

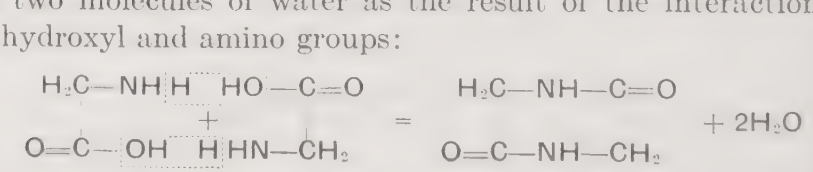
With acyl chlorides, compounds related to amides are formed:

$$CH_3COCl + NH_2CH_2COOH = CH_3CO.NHCH_2COOH + HCl$$
$$CH_3COCl + NH_3 = CH_3CO.NH_2 + HCl$$

The esters of amino acids are prepared by the application of one of the general methods of preparing esters, namely, the treatment of the mixture of an acid and an alcohol with hydrogen chloride. The product obtained in this case is the hydrochloride of the amino ester. The free ester can be isolated by careful treatment with an alkali. The esters of the amino acids can be distilled without decomposition under diminished pressure, whereas the free acids are decomposed when heated. This fact has been utilized in the separation of the amino acids which are obtained as the result of the hydrolysis of proteins.

354. The amino acids decompose with more or less readiness when heated. The changes which take place bear a striking analogy to those observed in the case of the hydroxy acids (**306**).

When the α-amino-acids are heated two molecules of the acid lose two molecules of water as the result of the interaction of the hydroxyl and amino groups:



The β-acids lose ammonia when heated:

$$NH_2.CH_2CH_2COOH = CH_2:CHCOOH + NH_3$$

The γ-acids lose water and form compounds called *lactams* on account of their relation to lactones, which are formed from γ-hydroxy acids:

$$NH_2.CH_2CH_2CH_2COOH = NH.CH_2CH_2CH_2CO + H_2O$$

355. Glycine, NH_2CH_2COOH, aminoacetic acid, can be obtained from glue or certain other proteins by boiling with dilute sulphuric acid. The acid has a sweet taste; it is often called glycocoll, the name being derived from the Greek words signifying "sweet" and "glue." It is obtained from a number of natural sources. It is formed as one of the products of hydrolysis of hippuric acid, $C_6H_5CONH.CH_2COOH$, which occurs in the urine of horses, and of taurocholic acid and glycocholic acid, which occur in the bile. It can be prepared synthetically from ammonia and chloroacetic acid. The acid crystallizes from water and melts with decomposition at 233°.

Glycine forms salts with acids, such as those of the composition $HCl.NH_2CH_2COOH$ and $HNO_3.NH_2CH_2COOH$. The copper salt, which crystallizes from water, has the formula $(NH_2CH_2COO)_2Cu.H_2O$.

It is probable that aminoacetic acid is itself a salt that results from the interaction of the amino group and the carboxyl group, which the acid contains. Such a salt would be decomposed when treated with a strong acid or base, and a salt with the acid or base would be formed. From this point of view, the formula of aminoacetic acid can be written as follows:

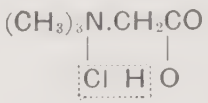
$$CH_2\begin{cases} NH_3^+ \\ COO^- \end{cases}$$

Sarcosine is a methyl derivative of glycine, $CH_3NH.CH_2COOH$. It is found in flesh and is a constituent of meat extract.

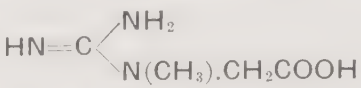
356. Betaïne, which occurs in the juice of the sugar beet and is the source of the trimethylamine made from the residue obtained in the preparation of sugar, has the structure represented by the following formula:

$$(CH_3)_3N.CH_2.CO$$
$$\qquad\qquad\quad O$$

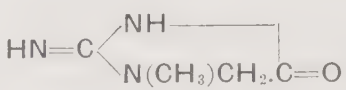
The structure assigned to betaïne follows from its synthesis from trimethylamine and chloroacetic acid, which unite and then lose hydrogen chloride:



357. Creatine is also one of the so-called "meat extractives." It is related to sarcosine and guanidine. Its formula is



Creatine passes by loss of water into *creatinine*, which is present in flesh, and in small quantity in urine. The formula assigned to creatinine is



358. Alanine, $CH_3.CHNH_2.COOH$, α-aminopropionic acid, may be prepared by the action of ammonia on α-chloropropionic acid. It is an important decomposition product of proteins. *Serine*, which is the β-hydroxyl derivative of alanine, is also obtained from proteins. It has been synthesized from glycolic aldehyde by the reactions indicated in the second method of preparing amino acids described above (**352**).

359. Leucine, $(CH_3)_2CH.CH_2.CHNH_2.COOH$, α-amino-isocaproic acid, is found in a number of the organs of the body, and is obtained from proteins by hydrolysis. It has been synthesized from isovaleric aldehyde. *Isoleucine* is an isomer of the formula $\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>\!CH.CHNH_2.COOH$. It has been shown that the isoamyl alcohol and active amyl alcohol which are the chief constituents of the fusel oil formed in the fermentation of grain are produced as the result of the decomposition of the proteins of the grain which yield leucine and isoleucine on hydrolysis. When sugar is fermented with pure yeast, amyl alcohols are not formed. In the presence of leucine, isoamyl alcohol, $(CH_3)_2CHCH_2CH_2OH$, and in the presence of isoleucine, active amyl alcohol, $CH_3.C_2H_5.CH.CH_2OH$, are formed.

360. Ornithine, $NH_2.CH_2.CH_2.CH_2.CHNH_2.COOH$, α,δ-diaminovaleric acid, and *lysine*, α,ϵ-diaminocaproic acid, are obtained from proteins. The former is converted into putrescine, $NH_2(CH_2)_4NH_2$, and the latter into cadaverine, $NH_2(CH_2)_5NH_2$, by putrefactive bacteria.

361. α-Asparagine is an example of an acid amide which contains an amino group. Its formula is

$$\begin{array}{l} CHNH_2.CONH_2 \\ | \\ CH_2.COOH \end{array}$$

Asparagine occurs in asparagus, beets, peas, beans, and in a great variety of plants. The NH_2 groups which asparagine contains, do not react alike. One is present in an amide group $CONH_2$; the other is joined to carbon which is not directly linked to oxygen. When asparagine is boiled with a solution of an alkali one-half of the nitrogen is removed as ammonia. The resulting product is a salt of aspartic acid:

$$\begin{array}{l} CHNH_2.COOH \\ | \\ CH_2.COOH \end{array}$$

The Effect of Structure on the Activity of Acids

362. Ionization Constants of Acids.—Acids vary greatly in the extent to which they undergo ionization when dissolved in water. Thus, acetic acid, $CH_3CO.OH$, is but slightly ionized, while trichloroacetic acid, $CCl_3CO.OH$, is ionized to a high degree. The difference in activity is the result of the replacement of the positive hydrogen atom by the negative chlorine atom.

The extent to which an acid is ionized varies with the concentration of its solution. The comparison of the ionization of two acids is simplified by the fact that a mathematical relation exists between the extent of the ionization of an acid and its concentration, which is represented by the formula

$$\frac{a^2}{v(1-a)} = K$$

where a is the fraction of the acid which is ionized, v is the volume of the solution which contains 1 gram-molecular weight

of the acid, and K is a constant.[1] It is seen from the formula that of two acids the one which is more highly ionized has the greater constant. The ionization constants of a number of acids will now be given to illustrate the effect of structure on the activity of acids and the effect of substituents on the nature of radicals.

Acid	$100K^{25°}$	Acid	$100K^{25°}$
H.COOH	0.021	$CH_3CH_2CH_2.COOH$	0.00150
$CH_3.COOH$	0.00181		
$C_2H_5.COOH$	0.00132	CH_3	
$C_3H_7.COOH$	0.00150	$>CH.COOH$	0.00141
$C_4H_9.COOH$	0.00156	CH_3	

In the first column the normal acids are given. It is seen that formic acid is a much stronger acid than acetic acid, which is but slightly more ionized than propionic acid.

The effect of substituents is shown by the following table:

Acid	$100K^{25°}$	Acid	$100K^{25°}$
$CH_3.COOH$	0.00181	$CH_2Br.COOH$	0.135
$CH_2Cl.COOH$	0.152	$CH_2(CN).COOH$	0.365
$CHCl_2.COOH$	5.14	$CH_2(OH).COOH$	0.0149
CCl_3COOH	121	$CH_2(SH).COOH$	0.0285

The replacement of a hydrogen atom in acetic acid by a chlorine atom increases the constant of the acid 86 times. The second and third atoms do not have as great an effect; the constant of dichloroacetic acid is about 33 times as great as that of chloroacetic acid, and that of trichloroacetic acid 23.5 times as great as that of the disubstituted acid. It should be pointed out that the constants for dichloro- and trichloro-acetic acid are rough approximations only, for the reason that highly ionized compounds do not behave in accord with the law upon which the calculation of the constant is based.

Bromoacetic acid is almost as strong as chloroacetic acid, while cyanoacetic acid is over twice as active as the latter. The $-C\equiv N$ radical is accordingly strongly negative. From this point of view it appears remarkable that hydrocyanic acid is such a weak acid. As the cyanogen radical has such strongly

[1] For the derivation of this formula the student should consult a textbook of physical chemistry

negative properties, it seems highly probable that it is not present in hydrocyanic acid, and that the acid has the structure H—N=C and not H—C≡N.

The relative effect of oxygen and sulphur is shown in the constants for glycolic acid and thioglycolic acid. When sulphur replaces the oxygen of the hydroxyl group it has a marked effect on the constant of an acid: the constant for thioacetic acid, $CH_3.CO.SH$, is 0.00046 while that of acetic acid is 0.000018.

The effect of the position of the substituent on the constant of an acid is shown in the following table:

Acid	$100K^{25°}$	Acid	$100K^{25°}$
$CH_3.CH_2.COOH$	0.00132	$HOOC.COOH$	10
$CH_3.CHOH.COOH$	0.0136	$HOOC.CH_2.COOH$	0.16
$CH_2OH.CH_2.COOH$	0.00295	$HOOC.CH_2CH_2.COOH$	0.0067
$CH_2OH.CHOH.COOH$	0.0223	$HOOC.(CH_2)_3.COOH$	0.00467

It is seen that the nearer the substituent is to the carboxyl group, the greater is its effect on the ionization constant.

The effect of a double bond is shown in the following table:

Acid	$100K^{25°}$	Acid	$100K^{25°}$
$CH_3.CH_2.COOH$	0.00132	$HC.COOH$ ‖ $HC.COOH$	1.15
$CH_2{=}CH.COOH$	0.0055		
$HC.COOH$ ‖ $HC.CH_3$	0.0020	$HC.COOH$ ‖ $HOOC.CH$	0.091
$HC.COOH$ ‖ $CH_3.CH$	0.0035		

The introduction of a double bond leads to an increased activity in the acid. The marked difference between the values of the constants of maleic and fumaric acid is noteworthy. The difference appears to be the result of the positions, with respect to each other, occupied by the two carboxyl groups. The stereochemical influence is marked in this case. In the tartaric acids this is not so; the ionization constants for *d*-tartaric acid and *l*-tartaric acid are the same, namely, 0.00097.

Problems

1. Write equations for reactions by which CH_3CH_2COOH can be converted into (*a*) $CH_3CHBrCOOH$, (*b*) CH_2BrCH_2COOH, (*c*) $CH_2{=}CH$-

COOH, (*d*) $CH_2OH.CH_2COOH$, (*e*) $CH_2BrCHBrCOOH$, (*f*) CH_2BrCH_2COBr. How could you distinguish by a chemical test (*g*) the compounds listed above under *a* and *b*, and (*h*) those under *c* and *d*?

2. Write equations for reactions by which CH_3CH_2OH may be converted into (*a*) $CH_2Br.CH_2OH$, (*b*) $CH_2OH.CH_2OH$, (*c*) $COOH.CH_2.CH_2OH$, (*d*) $CH_3.CH_2OC_2H_5$, (*e*) $C_2H_5OCH_2.CH_2OH$. (*f*) How could you distinguish from one another the compounds listed above?

3. Write equations for reactions by which CH_3CH_2COOH may be converted into (*a*) CH_3CHNH_2COOH, (*b*) $NH_2CH_2CH_2COOH$, (*c*) $CH_3CH_2CONH_2$. (*d*) How could you distinguish from one another the compounds listed above?

4. Indicate by equations how the following may be prepared from acetoacetic ester: (*a*) $CH_3COC_3H_7$, (*b*) $CH_3COCH(CH_3)_2$, (*c*) $(CH_3)_2CHCOOH$, (*d*) n-C_3H_7COOH, (*e*) C_8H_{18}, (*f*) $CH_3CH{=}CHC_2H_5$.

5. Write formulas for the compounds formed, if any, when the following are heated with an aqueous solution of sodium hydroxide: (*a*) $CH_2ClCOOC_2H_5$, (*b*) $CCl_3COOC_2H_5$, (*c*) $C_2H_4Cl.O.C_2H_5$, (*d*) CH_2BrCH_2OH, (*e*) $(C_2H_5)_2O$, (*f*) CH_3CONH_2, (*g*) NH_2CH_2COOH, (*h*) $ClCH_2CONH_2$, (*i*) $CH_3OCH_2.COOH$, (*j*) $HOCH_2COOC_2H_5$.

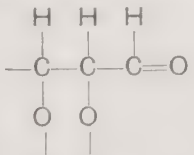
6. By what reactions could the following transformations be effected: (*a*) malic acid into maleic acid, (*b*) glycerol into β-iodopropionic acid, (*c*) lactic acid into pyruvic acid, (*d*) acetamide into methylamine, (*e*) hydracrylic acid into malonic acid?

7. Write out a statement of the effect of substituents on the ionization constants of acids under the following headings: (*a*) effect of nature of substituent, (*b*) effect of number of atoms of the substituent, (*c*) effect of the position of the substituent. (*d*) Arrange the following in an order showing increased effect on the constant: Cl, Br, CN, SH, OH, COOH, and a double bond.

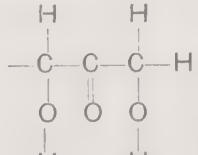
CHAPTER XV

CARBOHYDRATES

363. Many organic compounds are produced as the result of the growth of plants. The more important of these, such as starch, sugar, and cellulose, are called carbohydrates. The name was originally given to the members of this class on account of the fact that the hydrogen and oxygen which they contain are present in the proportion in which these elements are present in water. The relation is shown by writing the formula for sugar, $C_{12}H_{22}O_{11}$, as $C_{12}(H_2O)_{11}$; and for starch, $C_6H_{10}O_5$, as $C_6(H_2O)_5$. The formulas of certain carbohydrates which have been isolated from natural sources do not show the simple relation between the hydrogen and oxygen atoms indicated by the name. Rhamnose, for example, which is obtained from the bark of certain trees, has the formula $C_6H_{12}O_5$. A number of compounds which are not carbohydrates contain hydrogen and oxygen atoms in the relation of two of the former to one of the latter; the formula of acetic acid is $C_2H_4O_2$, of lactic acid, $C_3H_6O_3$, etc. Notwithstanding these facts the name carbohydrate is retained. The study of the structure of compounds of this class has made it possible to define the term more specifically. The *carbohydrates* are aldehyde alcohols, ketone alcohols, or compounds which are converted by hydrolysis into aldehyde alcohols or ketone alcohols. The carbohydrates contain or are converted by hydrolysis into compounds which contain the arrangement of atoms represented by the following formulas:



Aldehyde alcohol



Ketone alcohol

The carbohydrates, or *saccharides* as they are sometimes called, are divided into two classes: those which do not undergo

hydrolysis are called *monosaccharides*, and those which are converted into the latter by hydrolysis are called *polysaccharides*. When the monosaccharides contain the aldehyde group they are classed as *aldoses;* when they contain the ketone group they are called *ketoses*. The number of carbon atoms in a monosaccharide is indicated in its name; thus, glucose, $C_6H_{12}O_6$, is a *hexose*. *Tetroses*, *pentoses*, *heptoses*, *octoses*, and *nonoses* are known. When a polysaccharide yields two molecules of a monosaccharide on hydrolysis it is called a *disaccharide*. Cane sugar is a disaccharide, as on hydrolysis it is converted into one molecule of glucose and one molecule of fructose.

As the hexoses are the most important of the monosaccharides a few typical members of the class will be discussed in some detail.

Dextrose

364. Dextrose, *d*-glucose, $C_6H_{12}O_6$, occurs widely distributed in fruits, usually mixed with another sugar called levulose or *d*-fructose. It is an important constituent of honey, which contains in addition to dextrose, levulose, dextrin, and cane sugar. It is present in relatively large amounts in grapes; for this reason dextrose is often called "grape sugar." It is present in small quantities in normal urine, but the amount may increase up to 8 to 10 per cent in the case of patients suffering from diabetes.

Dextrose is formed as the result of the hydrolysis of a number of polysaccharides. Starch, dextrin, and maltose are completely converted into dextrose when heated with water in the presence of a small amount of acid. The reaction in the case of starch is represented by the equation

$$(C_6H_{10}O_5)_n + nH_2O = nC_6H_{12}O_6$$

and that for maltose by the equation

$$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6.$$

Other polysaccharides yield dextrose along with another hexose on hydrolysis. Cane sugar is converted in this way into dextrose and levulose:

$$C_{12}H_{22}O_{11} + H_2O = \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Levulose}}{C_6H_{12}O_6}$$

Milk sugar yields dextrose and galactose; the equation for the reaction is the same as that written for cane sugar.

Dextrose crystallizes with difficulty from water, in which it is very soluble. The crystals contain one molecule of water, and are in the form of microscopic six-sided plates, which grow in masses; they melt at 86°. They are obtained most readily by crystallizing dextrose from 80 per cent alcohol. Anhydrous dextrose is obtained from 95 per cent methyl or ethyl alcohol. In this form the carbohydrate melts at 146°. Pure dextrose is approximately three-fifths as sweet as cane sugar. It is optically active.

365. Specific Rotation of Optically Active Substances.—The extent to which polarized light is rotated by optically active substances varies with different substances. With any substance the angle of rotation depends upon the concentration of the solution, the length of the layer through which the light passes, the temperature, and the wave length of the light. In order to compare the rotatory power of different compounds standard conditions have been defined. The *specific rotation* of an optically active substance is measured by the angle of rotation which plane-polarized light of the wave length corresponding to that of the yellow D line of the solar spectrum undergoes in passing, at a temperature of 20°, through a decimeter column of a solution of the substance having the concentration of 1 gram in 1 c.c This is expressed by the equations

$$a = [\alpha]_D l \frac{w}{v} \text{ or } [\alpha]_D = \frac{av}{lw}$$

where a is the observed angle of rotation, $[\alpha]_D$ is the specific rotation, l length of the column in decimeters, w the weight of substance, and v the volume of the solution.

$[\alpha]_D$ for dextrose is 52.2° at 20°. If a substance is levorotatory its rotation is expressed as a negative angle, thus, for levulose $[\alpha]_D^{20°}$ is $-93°$.

In the case of optically active liquids the specific rotation is defined by the formula $[\alpha]_D = a/ld$, where l is the length of the column examined, and d is the density of the liquid.

Many optically active substances when dissolved in water form solutions which slowly change in rotatory power until a constant value is finally reached. This phenomenon is called *mutarotation.* When ordinary dextrose, which contains one molecule of water of crystallization, is dissolved in water, the specific rotation of the solution is 113.4° at 20° An anhydrous form of dextrose has been prepared which gives, as soon as dissolved, the specific rotation 19.7° at 20°. The solution obtained from either form of the carbohydrate, which on standing some hours shows the normal specific rotation, 52.3°, contains a mixture of the two forms in equilibrium. The

view has been put forward that carbohydrates which exhibit mutarotation may exist in tautomeric forms (**368**).

366. Preparation of Dextrose.—Dextrose is made commercially by hydrolyzing starch with dilute hydrochloric acid (1 to 3 per cent). The mixture is heated to boiling in an open vessel or with superheated steam in a closed vessel. The length of time of heating is determined by the nature of the product desired. If "glucose," which is the commercial name for the thick syrup formed as the result of the partial hydrolysis of starch, is to be made, the reaction is stopped when a test portion of the solution does not give the characteristic blue color which starch forms with iodine. The port-wine color which results indicates the presence of dextrin which is an intermediate product in the change of starch into dextrose. Glucose also contains some maltose, $C_{12}H_{22}O_{11}$. In making "grape sugar," which is almost pure dextrose, the hydrolysis is carried farther. The complete conversion of the starch into dextrose is shown by adding alcohol to the product of hydrolysis; if no precipitate is formed starch and dextrin are absent, as these substances are insoluble in alcohol. Grape sugar is usually obtained in the form of a compact mass of waxy texture. By allowing a concentrated solution of grape sugar to stand at about 35° in contact with a few crystals of dextrose, the larger part of the substance separates as a mass of minute crystals.

Glucose and grape sugar are obtained from the dilute solutions formed as the result of the hydrolysis, by evaporation in vacuum pans after the solutions have been neutralized with sodium carbonate, filtered, and decolorized by treatment with bone black.

Glucose has a number of important uses. As it is converted into alcohol by fermentation, it is frequently added to the liquids from which wine and beer are to be prepared, in order to increase the percentage of alcohol formed. It is used in dyeing with indigo, in the preparation of jellies and preserves, and as a thickening agent in certain pharmaceutical preparations. It is also used as a table syrup.

367. Structure of Dextrose.—Dextrose enters into a number of important reactions with other substances. Those which

have a bearing on the structure of the carbohydrate will be first considered. Dextrose is reduced by hydrogen, generated from sodium amalgam and water, to *d*-sorbitol, which is a hexahydroxy alcohol

$$CH_2OH.CHOH.CHOH.CHOH.CHOH.CH_2OH.$$

This transformation indicates that the carbon atoms in glucose are united in a straight chain.

By careful oxidation dextrose is converted into gluconic acid:

$$C_6H_{12}O_6 + O = C_6H_{12}O_7$$

The addition of one oxygen atom results in the formation of an acid. This fact indicates that glucose contains an aldehyde group:

$$-\overset{\overset{O}{\|}}{C}H + O = -\overset{\overset{O}{\|}}{C}-OH$$

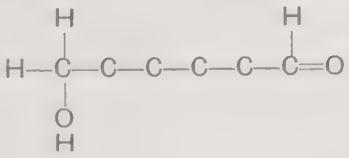
On further oxidation saccharic acid, a dibasic acid, is formed. The change in this case consists in the replacement of two hydrogen atoms by one oxygen atom:

$$C_6H_{12}O_7 + 2O = C_6H_{10}O_8 + H_2O$$

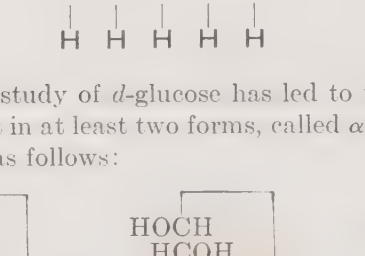
This reaction shows that gluconic acid and dextrose, from which it is prepared, each contain a primary alcohol group. The change which takes place consists in the conversion of this group into a carboxyl group:

$$-CH_2OH + 2O = -COOH + H_2O$$

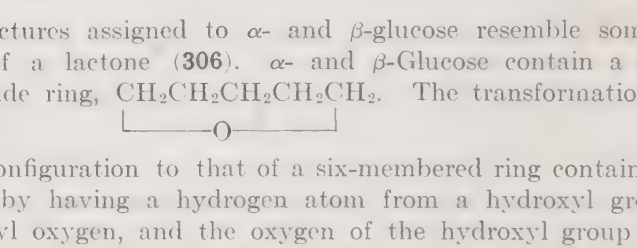
As the aldehyde group and the primary alcohol group are both univalent, they must be situated at the ends of the chain of carbon atoms in dextrose. From these facts, then, we draw the conclusion that in dextrose the atoms are united as indicated in the following arrangement:



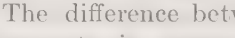
The relation which the oxygen atoms in dextrose bear to th rest of the molecule, is indicated by the fact that when the ca bohydrate is treated with acetic anhydride, in the presence of small amount of zinc chloride, five acetyl groups are introduce into the molecule. This reaction shows that dextrose contai five alcoholic hydroxyl groups. Taken in connection with th reactions just mentioned, it leads to a structure for dextro which is given in the following formula:



368. The extensive study of *d*-glucose has led to the conclusion that t carbohydrate can exist in at least two forms, called α and β. The structu assigned to these are as follows:



The structures assigned to α- and β-glucose resemble somewhat t structure of a lactone (**306**). α- and β-Glucose contain a substitut amylene-oxide ring, $CH_2CH_2CH_2CH_2CH_2$. The transformation from t



aldehyde configuration to that of a six-membered ring containing oxyg is effected by having a hydrogen atom from a hydroxyl group add the carbonyl oxygen, and the oxygen of the hydroxyl group add to end carbon atom. The difference between the α- and β-form consists the different arrangements in space of the hydrogen atoms and hydroxyl groups joined to the carbon atoms shown at the top of formulas. When either form is dissolved in water it passes in part into other. This explanation is given of the mutarotation shown by *d*-gluc (**365**). When the solution shows a constant rotation of 52.2° equilibri has been reached.

369. Chemical Properties of Dextrose.—The reactions dextrose are in accord with the formula which has been assign to it. It *reacts as an aldehyde* with an ammoniacal solution

silver oxide and with Fehling's solution. An alkaline solution of dextrose precipitates selenium, tellurium, gold, platinum, and certain other metals from their salts.

It *reacts as an alcohol* with acetic anhydride and forms a penta-acetate; methyl sulphate converts dextrose into an ether.

Dextrose *forms an oxime* with hydroxylamine, which melts at 138°, and a *phenylhydrazone*, which melts at 145°. Both compounds are very soluble in water. When dextrose is heated in aqueous solution with an excess of phenylhydrazine over that required to form the phenylhydrazone, a reaction takes place in which one molecule of the carbohydrate reacts with three molecules of the hydrazine. The substance formed is called an *osazone*. It is a compound which is difficultly soluble in water, crystallizes well, and has a definite melting point and a deep-yellow color. Other sugars form osazones, which can be readily purified. The determination of the melting points of the osazones serves as a convenient means of identifying sugars which either do not melt or cannot be readily obtained in pure condition.

370. *Osazones.*—In the conversion of a sugar into an osazone, a phenylhydrazone is first formed, the reaction being analogous to that between an aldehyde and phenylhydrazine:

$$CH_2OH(CHOH)_4CHO + C_6H_5NH.NH_2 = CH_2OH(CHOH)_4CH:N.NHC_6H_5 + H_2O$$

In the presence of an excess of phenylhydrazine, two hydrogen atoms are removed from the phenylhydrazone, and a molecule of phenylhydrazine is reduced to ammonia and aniline, $C_6H_5.NH_2$:

$$C_6H_5NH.NH_2 + 2H = C_6H_5NH_2 + NH_3$$

The product formed from the phenylhydrazone by the loss of two hydrogen atoms interacts with more phenylhydrazine and forms an osazone:

$$CH_2OH(CHOH)_3C:O + C_6H_5NH.NH_2 = CH_2OH(CHOH)_3C(:N.NHC_6H_5)CH:N.NHC_6H_5 + H_2O$$

The osazone formed from dextrose (*d*-glucose) is called *d*-glucosazone. It crystallizes from water in yellow needles and melts at 205°.

371. Dextrose forms addition products with certain salts, oxides, and anhydrides. A compound of the composition $2C_6H_{12}O_6.NaCl.H_2O$ is obtained in the form of crystals from diabetic urine. Other compounds with sodium chloride have the formulas

$$C_6H_{12}O_6.NaCl \quad \text{and} \quad C_6H_{12}O_6.2NaCl.$$

Compounds which contain calcium oxide, barium oxide, and zinc oxide are known. One of the compounds which contains calcium oxide has the formula $C_6H_{12}O_6.CaO$.

Dextrose is *fermented* by the enzyme *zymase*, which is present in yeast; the products are alcohol and carbon dioxide:

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$$

As the result of the action of the enzyme in putrid cheese, it is converted into lactic acid and butyric acid.

372. Enzymes.—The chemical change by which glucose is converted into alcohol and carbon dioxide by yeast is an example of what is called *fermentation*. The process consists in the conversion of an organic compound into simpler substances through the agency of living organisms or the products formed by the growth of such organisms. When fermentation was first studied it was thought that the changes produced were associated in some way with the life processes of the organism which induced fermentation. It was shown later, however, by Buchner, that fermentation was brought about in certain cases by complex substances produced by the living organism. By grinding yeast with sand and subjecting the resulting mixture to great pressure a juice was obtained which brought about the fermentation of glucose. It was shown by biological tests that the juice did not contain living cells or living protoplasm; its ability to ferment sugar solution was due to the presence of a complex organic substance of unknown composition. This substance, which is called *zymase*, is an enzyme. The term *enzyme* is applied to the substances secreted by living cells, which cause chemical change in the absence of the cell.

On account of their significance in many natural processes enzymes have been studied extensively, but up to the present

no pure compound of this class has been prepared. Willstaetter, who has extended markedly the knowledge of enzymes, is of the opinion that they are not carbohydrates or proteins, but contain a grouping of atoms that combines with, or has a special affinity for, a definite grouping in the substance acted upon. The activity of an enzyme depends on its colloidal nature; if this is destroyed, activity disappears.

Willstätter concentrated enzymes from natural sources by absorbing them on porous material and then removing the enzyme from the latter. Absorption took place in the presence of one concentration of hydrogen ions and release in the presence of another concentration. By many repetitions of this process preparations of a very high degree of activity were obtained.

Although their exact chemical nature has not been discovered, many important facts have been brought to light which make it possible to separate enzymes in a more or less pure condition from natural sources, to classify them, and to use them to bring about definite chemical transformations. The enzymes possess certain properties in common. They are substances which give colloidal solutions in water, dilute alcohol, mixtures of glycerol and water, and a solution of sodium chloride. They are precipitated from solution by alcohol and by a solution of ammonium sulphate. Enzymes act most rapidly at approximately the temperature of the animal body (37°); at 0° their activity almost vanishes and at 100° they are destroyed. After careful drying at room temperature enzymes can be heated to 100° without appreciable change.

The action of enzymes is catalytic and is markedly affected by other substances; some function only in the presence of dilute acids, while others require a neutral or alkaline solution. Their activity under these circumstances is affected by the degree of acidity or alkalinity of the solution. For example, in the preparation of lactic acid by the fermentation of sugar, calcium carbonate is added to neutralize the acid as it is formed; when the acidity reaches 1 per cent fermentation ceases. The activity of enzymes is destroyed by certain substances which act as poisons. It has been shown in the case of certain enzymes that two substances are present, both of which are necessary when

the enzymes function. One is called the enzyme and the oth the co-enzyme. Zymase has been separated into two part neither of which alone will bring about the fermentation sugar; but a mixture of the two acts normally.

Enzymes differ in the kind of chemical reaction which the bring about and the kind of substance which they affect. Fro the second point of view they are classified as (1) lipolyt enzymes, which bring about transformation in fats; (2) amy lolytic, which cause various kinds of transformations in ca bohydrates; (3) proteolytic, which affect proteins; and (glucoside-splitting enzymes, which cause the decomposition glucosides. The kinds of reactions induced by enzymes are (hydrolysis, (2) oxidation, (3) reduction, (4) coagulation, and (decomposition of the molecule without the agency of any othe substance. The enzymes that cause hydrolysis will also brin about the reverse reaction. For example, a lipase will induc either the hydrolysis of a fat or cause the formation of a fa from glycerin and a fatty acid.

The action of enzymes is more or less specific. Zymase, fo example, will not cause the alcoholic fermentation of all th hexoses. It appears that in most cases the stereochemic configuration of the molecule is an important factor in determi ing whether or not an enzyme will affect a particular carbohydra or protein.

In the discussion of the carbohydrates and proteins, a numbe of enzymes will be mentioned in connection with the consider tion of the particular compounds which they affect.

373. Glucosides.—Dextrose occurs in nature in combinatio with various substances. These compounds, which are calle glucosides, are in most cases very complex in composition. Bu a few can be mentioned here. *Aesculin*, $C_{15}H_{16}O_9.1\frac{1}{2}H_2O$ occurs in the bark of the horse-chestnut tree; on hydrolysis yields dextrose and aesculetin, $C_9H_6O_4$. *Amygdalin*, $C_{20}H_{27}$ $NO_{11}.3H_2O$, occurs in bitter almonds and in the kernels peaches, plums, and cherries. It is decomposed by dilut acids into glucose, benzaldehyde, C_6H_5CHO, and hydrocyani acid. The hydrolysis can be brought about also by dilute acid or the enzyme *emulsin*. *Myronic acid*, $C_{10}H_{17}NS_2O_9.H_2O$, found as a potassium salt in black mustard seed. When hydr

lyzed by the enzyme *myrosin*, it is converted into dextrose, potassium sulphate, and allyl isothiocyanate, $C_3H_5.NCS$.

d-Fructose

374. *d*-Fructose, fruit sugar, $C_6H_{12}O_6$, occurs widely distributed in plants associated with dextrose and cane sugar. It is usually called *levulose* on account of the fact that it is levorotatory: $[\alpha]_D = -93°$. In the systematic naming of the monosaccharides the letter prefixed to the name does not indicate the direction in which the carbohydrate rotates the plane of polarized light. *d*-Fructose is so called because it can be formed from *d*-glucose. The alcohol formed by the reduction of *d*-glucose is *d*-sorbitol, and the acids formed by its oxidation are *d*-gluconic acid and *d*-saccharic acid. The names of the products formed by the reduction or oxidation of *l*-glucose and *dl*-glucose are likewise prefixed by the letters *l* or *dl*, respectively.

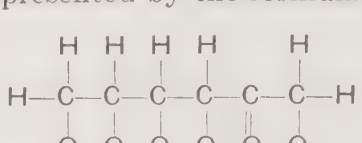
Levulose is a product of the hydrolysis of a number of carbohydrates. Cane sugar yields dextrose and levulose, and raffinose, a trisaccharide, yields levulose, dextrose, and galactose. Levulose is best prepared by hydrolyzing with dilute sulphuric acid inulin, a polysaccharide which occurs in dahlia tubers:

$$(C_6H_{10}O_5)_x + xH_2O = xC_6H_{12}O_6$$

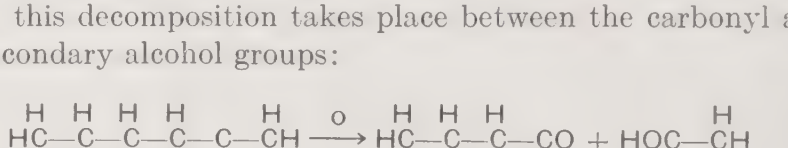
Levulose crystallizes in fine, colorless, rhombic needles, which melt at 104°. It is converted by yeast into alcohol and carbon dioxide and is the sweetest of all the sugars. It has been separated from the mixture of substances formed when an aqueous solution of formaldehyde and calcium hydroxide is allowed to stand (**182**).

375. Structure of *d*-Fructose.—As *d*-fructose yields *d*-sorbitol and *d*-mannitol on reduction, it must contain a straight chain of six carbon atoms. Acetic anhydride converts the carbohydrate into a penta-acetate, a fact which indicates that it contains five hydroxyl groups. On oxidation *d*-fructose does not yield an acid which contains six carbon atoms; it is, therefore, not an aldehyde. It is a ketone, however, as it forms a phenylhydrazone. The oxidation products vary with the nature of the oxidizing agent; mercuric oxide in the presence of barium hydroxide yields trihydroxybutyric acid and glycolic acid. All

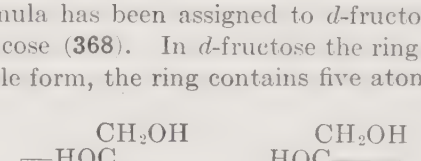
the facts stated lead to the conclusion that the structure of *d*-fructose is best represented by the formula:



The formation of glycolic acid and trihydroxybutyric acid as the result of the oxidation of fructose can be readily interpreted. It will be remembered that when ketones are oxidized two acids are formed as the result of the splitting of the molecule at the carbonyl group. In the oxidation of fructose by mercuric oxide, this decomposition takes place between the carbonyl and the secondary alcohol groups:



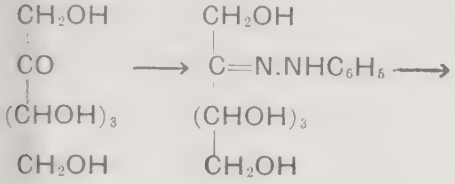
376. A ring formula has been assigned to *d*-fructose, somewhat like the one given to *d*-glucose (**368**). In *d*-fructose the ring contains six atoms; in γ-fructose, the labile form, the ring contains five atoms:

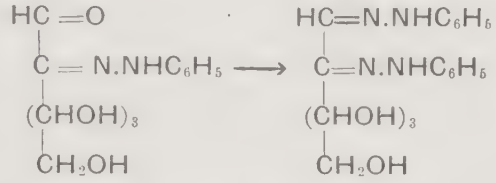


d-Fructose contains a substituted amylene-oxide ring (five carbon atoms). γ-Fructose contains a substituted butylene-oxide ring.

377. Chemical Properties of *d*-Fructose.—The carbohydrate forms a phenylhydrazone when treated with phenylhydrazine; when heated in aqueous solution with an excess of the hydrazine, an osazone is formed, which is identical with *d*-glucosazone. The reaction in this case is explained in the following manner: A phenylhydrazone is first formed as the result of the interaction of the carbonyl group and phenylhydrazine. Excess of the latter oxidizes the primary alcohol group to an aldehyde group, which

reacts with more phenylhydrazine in the usual way. The changes are expressed by the following formulas:





Methylphenylhydrazine, $C_6H_5.CH_3.NNH_2$, forms yellow osazones with ketoses but not with aldoses, which are converted into colorless hydrazones. It is possible, therefore, to distinguish and separate the two classes of carbohydrates by this reagent.

d-Fructose reduces Fehling's solution. It will be recalled that most ketones are not oxidized by this reagent (**205**). While ketones which contain the arrangement of atoms represented by the symbols $—CH_2—\overset{\overset{O}{\|}}{C}—CH_2—$ are not affected by mild oxidizing agents, those which contain a hydroxyl group linked to a carbon atom adjoining a carbonyl group, $—\overset{\overset{H}{|}}{\underset{\underset{O}{|}}{\overset{\overset{O}{\|}}{C}}}—C—CH_2—$, are readily oxidized.

378. *i*-Fructose, $C_6H_{12}O_6$, is formed as the result of the polymerization of formaldehyde. This takes place when a solution of the aldehyde which is saturated with calcium hydroxide is allowed to stand some time. The product of the polymerization, called *formose*, is a mixture of sugars which contains *i*-fructose. The carbohydrate is also formed by the action of a 1 per cent solution of sodium hydroxide on glyceric aldehyde, $CH_2OH.CHOH.CHO$. On account of the fact that the synthesis in this way was effected from acrolein, the sugar was originally called

acrose. Investigation proved later that acrose is a mixtur which contains *i*-fructose.

379. *d*-Galactose, $C_6H_{12}O_6$, is formed along with dextrose b the hydrolysis of milk sugar (lactose), $C_{12}H_{22}O_{11}$, and is a produc of the oxidation of dulcitol, a hexahydroxy alcohol which occur in certain plants. Galactose forms crystals which melt at 168 It is dextrorotatory, $[\alpha]_D = 79.3°$, undergoes fermentation, an is an aldose. Oxidizing agents convert *d*-galactose into *d*-gal actonic acid, $CH_2OH(CHOH)_4COOH$, and into mucic acid $COOH.(CHOH)_4.COOH$.

380. The Stereochemistry of the Hexoses.—The formul assigned to the aldoses indicates that there should be 16 differen arrangements of the atoms in space, and consequently 16 stereo isomeric compounds of the structure $CH_2OH(CHOH)_4CHO$ should be capable of existence. Eleven aldohexoses, and fiv racemic forms made by the combination of dextro and lev modifications have been prepared. Among these are *l*-glucose *i*-glucose, *l*-galactose, *i*-galactose, and the three forms of man nose. All these forms may be reduced to hexahydroxy alcohol and oxidized to pentahydroxy-monocarboxylic acids.

381. The stereochemical open chain formulas assigned to dextrose *d*-mannose, *d*-galactose, and levulose are as follows:

CHO	CHO	CHO	CH_2OH
HCOH	HOCH	HCOH	CO
HOCH	HOCH	HOCH	HOCH
HCOH	HCOH	HOCH	HCOH
HCOH	HCOH	HCOH	HCOH
CH_2OH	CH_2OH	CH_2OH	CH_2OH
Dextrose	*d*-Mannose	*d*-Galactose	Levulose

The consideration of the methods used in arriving at these conclusion is beyond the scope of this book. The formulas are of interest, however in connection with the study of the fermentation of monosaccharides by zymase. (Sec. **372**). Dextrose, *d*-mannose, and levulose, all of which readily undergo alcoholic fermentation, have the same stereochemical arrangemen of hydrogen and hydroxyl groups around the first four carbon atoms as w pass from the end of the chain where the primary alcoholic group is situated The carbohydrates the formulas of which are the mirror images of the thre given above, are not fermented by yeast. *d*-Galactose is converted int alcohol and carbon dioxide slowly by zymase, but it is not fermented b certain yeasts that affect the other three.

It will be recalled that the enzymes produced by certain organisms destro rapidly *l*-tartaric acid and scarcely affect the dextro form of the acid: an

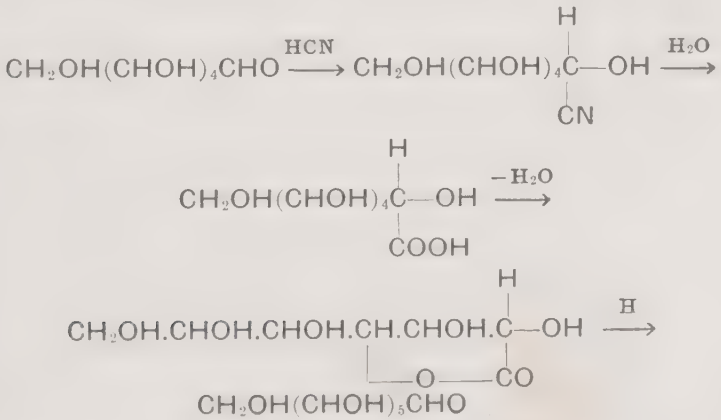
he reverse is true. Such facts as these are of the greatest importance in iological chemistry. Many of the transformations that take place in the nimal body, those of both decomposition and synthesis, are brought about hrough the agency of enzymes. It has been found that the action of such atalytic agents on proteins is also selective according to the stereochemical onfiguration of the molecules involved. Whether or not a compound can ndergo transformation in the body, and thus serve as a food, appears in nany cases to be traceable to the presence or absence of an enzyme capable f bringing about such transformations. The subject is a difficult one to nvestigate and much remains to be done. Much has been accomplished y Emil Fischer, however, in the field of carbohydrate chemistry from this oint of view.

Synthesis of Monosaccharides

382. A number of methods of synthesizing monosaccharides as been devised. The simplest of these is the oxidation of a exahydroxy alcohol to the corresponding aldehyde:

$$CH_2OH(CHOH)_4CH_2OH + O = CH_2OH(CHOH)_4CHO + H_2O$$

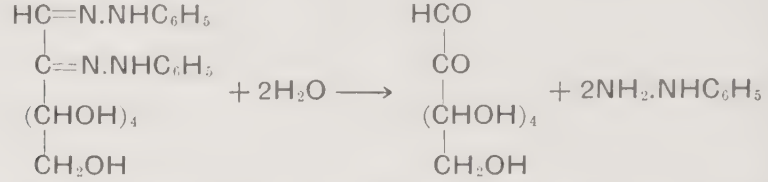
A second method, which is important on account of the fact hat it serves to pass from one sugar to another containing one nore carbon atom, is based on the reaction which aldehydes nd ketones undergo with hydrocyanic acid. The steps in the rocess can be best understood from an examination of the formulas of the substances involved in a typical example:



he steps are these: hydrocyanic acid is first added to the aldeyde group, the nitrile is next converted into an acid by hydrolsis, the acid which results loses water and passes into a γ-lactone, nd finally this, on reduction, yields an aldehyde. In this way

a hexose can be converted into a heptose. It should be noted that the process involves the application of reactions which have already been emphasized in the case of simple compounds.

A third synthetic method serves to convert an aldose into a ketose. When an osazone is warmed with concentrated hydrochloric acid, the phenylhydrazine residues are replaced by oxygen atoms and a compound is formed which is called an *osone:*

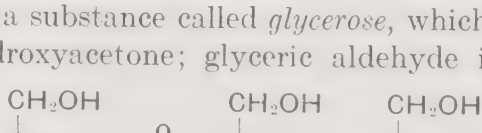


When an osone is treated with zinc and acetic acid the aldehyde group which it contains is reduced to a primary alcohol group; the resulting compound is a ketose. In this way *d*-glucose can be converted into *d*-fructose.

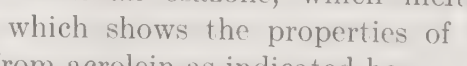
A fourth method is used to convert a ketose into an aldose. The ketose is reduced by sodium amalgam to a hexahydroxy alcohol; this on oxidation yields a monobasic acid, which is converted into a lactone; and, finally, the lactone is reduced to an aldehyde, which is an aldose.

Trioses, Tetroses, Pentoses

383. Compounds which contain the groups CHOH.CHO and CHOH.CO.CHOH show many of the properties of the hexoses. When glycerol is treated with mild oxidizing agents it is converted into a substance called *glycerose*, which consists essentially of dihydroxyacetone; glyceric aldehyde is also formed.



Glycerose forms an osazone, which melts at 131°. Glyceric aldehyde, which shows the properties of the aldoses, may be prepared from acrolein as indicated here:



384. Erythrose, $C_4H_8O_4$, is obtained as the result of the oxidation of erythritol, a tetrahydroxy alcohol. A tetrose can be formed by the polymerization of glycolic aldehyde. The reaction is an example of the aldol condensation (**189**):

$$CH_2OH.\overset{H}{\underset{|}{C}}:O + CH_2OH.CHO = CH_2OH.\overset{H}{\underset{|}{C}}\!-\!OH \quad \text{(CHOH.CHO)}$$

As in the simple condensation of aldehyde itself, a molecule of the aldehyde adds to the CHO group. In the addition a hydrogen atom unites with the oxygen, and the rest of the molecule to the carbon atom.

385. Arabinose and xylose, $C_5H_{10}O_5$, are stereoisomeric pentoses, which have been shown to have the structure

$$CH_2OH.CHOH.CHOH.CHOH.CHO$$

by the methods which have been illustrated in the case of the aldohexoses. Both carbohydrates are formed as the result of the hydrolysis of natural polysaccharides called pentosans; gum arabic, the husks of cottonseed, the residue from sugar beets after the removal of sugar, and cherry gum give arabinose, and straw, wood, bran, and other substances give xylose, which is now manufactured from cottonseed hulls. *Rhamnose* is a methyl derivative of a pentose, $CH_3.C_5H_9O_5$; it is obtained by the hydrolysis of a number of natural substances. All pentoses exhibit a reaction which serves to distinguish them from the other sugars. When a pentose or a pentosan is heated with dilute sulphuric acid, furfural is formed:

$$C_5H_{10}O_5 = C_5H_4O_2 + 3H_2O$$

The structure of furfural has been determined to be that represented by the formula

$$\begin{array}{l} CH{=}C.CHO \\ \quad\quad\quad\ \ O \\ CH{=}CH \end{array}$$

The presence of the aldehyde is shown by treating the product of the reaction with aniline, $C_6H_5.NH_2$, and hydrochloric acid with these reagents the aldehyde produces an intense red dye;

When warmed with hydrochloric acid and phloroglucinol (**550**) pentosans and pentoses produce a cherry-red coloration.

Disaccharides

386. A number of disaccharides occur in nature widely distributed in plants, and others are formed in the partial hydrolysis of polysaccharides. The members of this class of compounds differ among themselves in chemical properties; some, like cane sugar, do not reduce Fehling's solution, while others, like milk sugar, are oxidized by this reagent. The more important disaccharides are cane sugar, milk sugar, and maltose. They will be described as they are typical members of the class.

Sucrose (cane sugar, saccharose), $C_{12}H_{22}O_{11}$, occurs in sugar cane, beets, sorghum, the sugar maple, coffee, walnuts, almonds, and in many other substances. It is present in the blossoms of many plants, and is a constituent of honey. Sucrose crystallizes from water in well-formed monoclinic prisms. It is soluble in about one-half its weight of cold water; at 50° it is soluble in one-fourth its weight of water. Sucrose melts at 186°, and on cooling solidifies to a white glassy mass. If sugar is heated at or just above its melting point for some time, it solidifies on cooling to a light-brown transparent mass, which is called *barley sugar*. When heated to 210° it loses water and forms an amorphous light-brown substance called *caramel*, which is much used as a flavoring and coloring material. As the temperature is increased, deep-seated decomposition takes place; gases are evolved, the substance darkens in color, and finally a residue of carbon remains. Among the products of decomposition have been isolated carbon dioxide, carbon monoxide, methane, ethylene, acetylene, water, acetone, formic acid, acetic acid, aldehyde and acrolein. Sucrose is dextrorotatory: $[\alpha]_D^{20°} = 66.4°$.

387. Sugar is usually prepared from sugar cane, which contains about 14 per cent sugar; or from beets, which contain from 12 to 15 per cent sugar. The process employed in the extraction of sugar from beets is in general the same as that used when sugar cane is the source of the carbohydrate. The details are different, however, on account of the fact that beets contain certain substances which render the preparation of pure sugar more difficult. In brief, the process consists in the separation of the juice from the insoluble woody fiber, the precipitation from the solution of soluble acids and albumi-

nous substances, the evaporation of the solution to crystallization, and the separation of the crystals from the mother liquor. When sugar cane is used, the juice is expressed by passing the cane through rolls; in the case of beets the sugar is removed by extracting with water the beets which have been cut into very small pieces. The solution is next treated with milk of lime and heated to boiling when the calcium salts of the acids present, such as phosphoric, oxalic, and citric acids, are precipitated along with the organic nitrogenous substances and gums. The excess of calcium is removed by passing carbon dioxide through the liquid, which is then separated from solid material by filter pressing. The clarified juice is, at times, treated with sulphur dioxide to bleach any coloring matter present. The clear solution, which should be slightly alkaline in order to prevent hydrolysis of the sugar when it is heated, is evaporated to crystallization in "vacuum pans," from which the water is removed by boiling the liquid under diminished pressure. At the lower temperature thus obtained, the sugar is not greatly affected. When a solution of sugar is evaporated to crystallization in an open vessel, partial decomposition takes place and a brown color is produced. The crystals which separate on cooling are freed from the mother liquor by means of centrifugal machines. The liquid obtained in this way is called *molasses;* it contains 45 to 50 per cent sucrose and varying amounts of invert sugar, which is a mixture of dextrose and levulose. The molasses obtained from sugar cane is used as a table syrup or in the manufacture of rum; that from beets cannot be used for these purposes, as it contains substances which possess a disagreeable odor. Molasses from both sources is used for making alcohol.

The sugar obtained by the method outlined is not pure; it is brown and contains some syrup in which a number of substances is present. In order to convert it into granulated sugar it is refined. This process consists in dissolving the sugar in water, decolorizing the solution by treatment with bone black, and crystallizing after evaporation in vacuum pans.

388. Chemical Properties of Sucrose.—Sucrose, like dextrose and other carbohydrates, forms compounds with bases. A number of sucrates (saccharates) which contain calcium have been described. Those of the composition represented by the formulas, $C_{12}H_{22}O_{11}.CaO.2H_2O$ and $C_{12}H_{22}O_{11}.2CaO$, are soluble in water. When a solution containing a soluble calcium sucrate is heated to boiling, the salts are decomposed and a difficultly soluble salt of the formula $C_{12}H_{22}O_{11}.3CaO.3H_2O$ is precipitated. Calcium salts of sucrose are formed in the manufacture of sugar when the juice of sugar cane is clarified with lime, but are decomposed in the subsequent treatment with carbon dioxide. Strontium and barium also form sucrates. Tricalcium sucrate or tristrontium sucrate is used at times in the separation of sugar

from molasses which cannot be brought to crystallization. Sucrose forms well-crystallized compounds with salts, such as $C_{12}H_{22}O_{11}.NaCl.2H_2O$.

The reactions of sucrose indicate clearly that it contains alcoholic hydroxyl groups. Like other polyhydroxy alcohols it prevents the precipitation of the hydroxides of many metals by sodium hydroxide. It is converted by acetic anhydride into acetates; the one containing the largest number of acetyl groups has the composition $C_{12}H_{14}O_{11}(CH_3CO)_8$.

Sucrose is easily oxidized. The more powerful oxidizing agents, such as chromic acid and potassium chlorate, react with explosive violence. Nitric acid acts energetically, and yields oxalic acid and saccharic acid. Sucrose does not, however, reduce Fehling's solution. This fact is important, as it indicates that sucrose is not an aldehyde and does not contain the arrangement of atoms which is characteristic of a ketose, —CHOH—CO—CH_2OH. This conclusion is strengthened by the fact that sucrose does not form a hydrazone with phenylhydrazine.

Sucrose is hydrolyzed when heated with water in the presence of an acid, the products being dextrose and levulose:

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

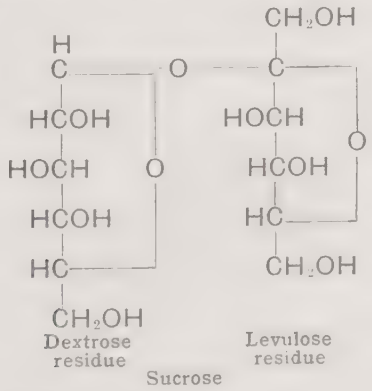
The mixture formed is called *invert sugar*, and the process is known as *inversion*. These names are applied on account of the fact that the direction of the rotation of the plane of polarized light caused by the mixture of the products of hydrolysis is different from that produced by sucrose. Sucrose is dextrorotatory, $[\alpha]_D = +66.5°$, while a mixture of equal amounts of dextrose and levulose is levorotatory. The specific rotation of invert sugar is the difference between the rotation caused by dextrose, $[\alpha]_D = +52.3°$, and that caused by levulose, $[\alpha]_D = -93°$.

The effect of acids on the hydrolysis of cane sugar by water has been carefully studied. It has been found that the rate of the reaction is determined by the nature of the acid used. A comparison of the rate at which the hydrolysis proceeds when molecular quantities of a number of acids are used, brings out the fact that the rate is proportional to the concentration

of the hydrogen ions produced as the result of the dissociation of the acid. The catalytic agent is, therefore, the hydrogen ion.

Sucrose does not ferment when treated with *zymase*, the enzyme which brings about the conversion of dextrose and levulose into alcohol and carbon dioxide. It does ferment, however, under the influence of ordinary yeast, which contains, in addition to zymase, another enzyme, called *invertase* on account of the fact that it causes the inversion of sucrose to dextrose and levulose.

389. The *structure of sucrose* has not been definitely established. The reactions of the carbohydrate indicate that it contains eight hydroxyl groups and that it does not contain an aldehyde or ketone group. As it yields dextrose and levulose by the addition of one molecule of water, it may be considered as an anhydride of these hexoses. It is apparent that the carbonyl groups which dextrose and levulose contain are involved in the building up of sucrose from these hexoses by the elimination of water. It has not been possible to effect this union in the laboratory, although it takes place, in all probability, in growing plants. Dextrose and levulose are found in unripe fruit; as the fruit ripens these carbohydrates decrease in amount and sucrose is formed. As hydrolysis of sucrose is effected with ease, it is probable that the union of its constituents is effected through oxygen atoms in the way indicated in the case of the glucosides. The structure assigned to sucrose as the result of these considerations is that represented by the following formula:



390. Quantitative Determination of Sucrose.—The purity of a sample of sugar, or the amount of sugar in a mixture, is estimated by determining the

effect of a solution of the substance to be analyzed on polarized light. If other optically active substances are present, they must be removed or their effect determined. The instrument used is a saccharimeter. This is a polariscope provided with a scale so graduated that the percentage of sugar is read off directly when a solution prepared by dissolving a definite weight of the product to be analyzed in a definite volume of water is examined in the instrument. If the product contains albuminous substances which render it more or less opalescent, it is treated with a solution of basic lead acetate, or aluminium hydroxide, which precipitates such substances. If it is colored, the solution is filtered through bone black. When a mixture like molasses, which contains, in addition to sucrose, optically active carbohydrates, is to be analyzed, the rotation produced by the solution is first determined; the sugar in the mixture is next inverted, and the rotation of the resulting solution determined. From these two results the amount of sugar present can be calculated.

391. Lactose (milk sugar), $C_{12}H_{22}O_{11}.H_2O$, occurs in the milk of mammals, in which it is present to the extent of from 3 to 5 per cent. It is obtained as a by-product in the manufacture of cheese. When rennet is added to milk, the casein and fat which the milk contains are precipitated. The liquid, called "whey," after separation from the solid material by pressure, is neutralized with calcium carbonate, filtered, and evaporated to crystallization. The lactose so obtained forms large, hard, rhombic crystals, which contain one molecule of water of crystallization.

Lactose is stable when heated to 100°; above this temperature it loses water slowly, and at 130° is converted into an anhydrous variety. As the temperature is raised, decomposition begins, and at 170° to 180° the so-called lacto-caramel is formed, which melts at 203°. Lactose has a slightly sweet taste. It is soluble in about 6 parts of cold water, and in about 2 parts of boiling water. Lactose is dextrorotatory and exhibits the phenomenon of mutarotation; $[\alpha]_D = 52.5°$.

Lactose is converted by hydrolysis into dextrose and galactose:

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

It reduces Fehling's solution. As the relation between the weight of copper reduced and the weight of the sugar oxidized is definite under fixed conditions, Fehling's solution is used in determining the amount of lactose present in milk.

Lactose forms a phenylhydrazone, osazone, and osone. The composition of these substances indicates that lactose contains one free carbonyl group. It is an anhydride of dextrose and galactose, in which one carbonyl group is involved in the union of the molecules, and one is free. The structure of the products formed on oxidizing lactose indicates that the free carbonyl group is in that part of the molecule which yields dextrose on hydrolysis.

Lactose is not fermented by ordinary yeast, but is converted into lactic acid by the so-called lactic ferment, which is found in sour milk.

392. Maltose, $C_{12}H_{22}O_{11}.H_2O$, is formed as the result of the action upon starch of the *diastase* in malt, the *ptyalin* in saliva, and other ferments, and in the partial hydrolysis of starch and dextrin by acids. It is present in commercial glucose, in beer, and probably in bread. It is manufactured on a large scale in the preparation of alcohol and alcoholic beverages. Maltose crystallizes from water, in which it is readily soluble, in plates, which contain one molecule of water of crystallization. It is obtained from alcohol in wart-like aggregates which are anhydrous. Maltose is dextrorotatory, and shows mutarotation; for the anhydrous form $[\alpha]_D^{20^\circ} = 136^\circ$.

Maltose yields dextrose on hydrolysis. It reduces Fehling's solution, forms a phenylhydrazone, osazone, and osone. It is, accordingly, a glucoside of *d*-glucose, and contains one carbonyl group.

Maltose is fermented by yeast, and is converted almost wholly into alcohol and carbon dioxide.

393. The Synthesis of Disaccharides.—Many attempts have been made to synthesize sucrose from dextrose and levulose, and to prepare other disaccharides from the constituents which they yield on hydrolysis. A synthesis of sucrose has been described recently, but the results have not yet been confirmed by independent investigators. A synthesis of gentiobiose, a carbohydrate which is obtained from the glucoside gentianose has been successful. Compounds of this class which do not occur in nature have been made; the methods used have been chemical or biochemical with the aid of enzymes. Fischer prepared, for example, a disaccharide by treating the tetra-acetylmono-

bromo derivative of dextrose with silver carbonate; the halogen atoms were removed, union of the two molecules was effected through oxygen and an octa-acetyl derivative of a sugar containing 12 carbon atoms was formed. The product when carefully hydrolyzed in the presence of barium hydroxide was converted into a disaccharide.

When a solution of dextrose is allowed to stand for a month or more with emulsin, a glucoside-splitting enzyme, gentiobiose, the carbohydrate mentioned above, is produced. It is probable that other disaccharides have been formed in this way, but their isolation from the large amount of the monosaccharides present prevented their satisfactory identification.

Trisaccharides

394. Raffinose, $C_{18}H_{32}O_{16}.5H_2O$, is the most important trisaccharide. It yields on hydrolysis levulose, dextrose, and galactose. Raffinose occurs in the molasses obtained in the manufacture of sugar from beets, in cottonseed, in barley, and in other grains. The hydrated crystals of raffinose lose their water at 100°. The anhydrous carbohydrate melts at 119°. Raffinose is dextrorotatory; for the hydrated form $[\alpha]_D^{20°} = 104.5°$. It does not reduce Fehling's solution.

Polysaccharides

395. The polysaccharides are carbohydrates of high molecular weight in which the carbon, hydrogen, and oxygen are present in the proportion represented by the formula $C_6H_{10}O_5$. Some of the members of the class are probably formed by the condensation of a large number of molecules of hexoses or pentoses with the elimination of water. Starch and cellulose are examples which are important constituents of plants. Other polysaccharides that are simpler in composition result from the partial hydrolysis of the more complex forms; the dextrins are examples. On complete hydrolysis the polysaccharides yield hexoses or pentoses.

396. Starch, $(C_6H_{10}O_5)_x$, occurs in nearly all plants, being present in large proportion in certain roots and seeds. It is manufactured from corn, wheat, potatoes, arrowroot, rice, and

certain varieties of palm trees. It is present in the plant as granules, the form and size of which vary with the plant. It is possible in most cases to determine the source of a sample of starch by a microscopic examination.

In the United States the chief sources of starch are corn and wheat; in Europe potatoes, rice, and wheat are used. Corn contains about 54 per cent of starch, while potatoes yield about 15 per cent of their weight of the carbohydrate. The separation of starch from the other substances present in the grain or tuber is accomplished largely by physical means: grinding, washing with water, and so forth. When corn is used it is steeped in warm water for a number of days. During this time much of the oil is removed, and the gluten and albuminous matter soften as the result of fermentation. The grain, mixed with water, is next ground in roller mills. The product is then passed over bolting cloth, through which the finely divided starch passes. The starch is washed with sodium hydroxide, stirred with water, and then allowed to settle. When the gluten, which deposits first, has settled, the supernatant liquid containing the starch in suspension is drawn off. Repetition of this process yields a product free from impurities. The starch as finally dried contains about 12 per cent of water.

Starch is extensively used as food, for laundry work, and in the preparation of glucose. The lower grades of starch are used in the textile industries for finishing cotton cloth. For this purpose rice starch is preferred. The starches obtained from different sources have slightly different properties. That obtained from wheat is used in making paste on account of its marked adhesive property. Sago, which is chiefly used as food, is a starch prepared from the pith of several varieties of palm trees; it swells in hot water without losing its globular form. Arrowroot starch is used for food and for laundry work and sizing purposes; it forms an unusually stiff jelly. Tapioca is prepared from cassava starch, which is obtained from the root of several plants which grow in tropical countries. It is made by stirring the moist hot starch until the granules burst and adhere together in irregularly shaped, translucent kernels. The starch which is generally used in toilet powders is that obtained from rice.

When starch is heated with water the granules swell and form a gelatinous mass as the result of the bursting of the membrane of cellulose which envelops the granules; on longer heating a

small amount of starch passes into solution. When treated with cold hydrochloric acid for a number of days, starch is changed into a variety which is soluble in water. At 200° to 250° starch is changed into dextrin; at a higher temperature it chars. Starch does not reduce Fehling's solution, does not react with phenylhydrazine, and is not fermentable. It is readily hydrolyzed by acids and enzymes. *Diastase* and *ptyalin*, which is the characteristic enzyme of saliva, convert starch into maltose and dextrin. It is changed into dextrin, maltose, and glucose when heated with dilute acids. The proportion of the products of hydrolysis formed is determined by the conditions. The final product is glucose.

Starch gives a characteristic blue color with iodine; the test is more delicate in the presence of an iodide. The nature of the compound has not been definitely established.

Starch is determined quantitatively by converting it into glucose and determining the latter by means of Fehling's solution or optical analysis.

397. Dextrin is made by heating starch to 200° to 250°. The product prepared in this way has a light-brown color. A lighter-colored dextrin is obtained by heating to 140° to 170° starch which has been moistened with nitric or hydrochloric acid and dried at 50°. The formula of dextrin has not been definitely established; there is some evidence, however, in favor of the formula $C_{31}H_{62}O_{31}$. It is probable that a number of dextrins exist.

Dextrin dissolves in cold water and forms a thick syrup, which has strong adhesive properties. It is used for thickening colors in calico printing, and in making the mucilage which is used on postage stamps. Dextrin syrups are also employed in brewing, for thickening tanning extracts, and in confectionery.

One variety of dextrin is dextrorotatory, $[\alpha]_D = 196°$; it forms a phenylhydrazone, reduces Fehling's solution, and gives a yellow color with alkalies. It, therefore, contains a free carbonyl group. Dextrin gives with a solution of iodine a color which varies from violet to red.

398. Glycogen, $(C_6H_{10}O_5)_x$, is a carbohydrate, chiefly of animal origin, which resembles starch in some of its properties. It occurs in the liver, and in smaller proportion in the blood,

spleen, kidneys, pancreas, and brain. It is found in a large number of fungi, where it seems to take the place of starch in higher plants. It also occurs in scallops and in certain insects. Glycogen is a white amorphous powder, which forms an opalescent solution with water. It is strongly dextrorotatory, the specific rotation varying with the concentration. An aqueous solution of glycogen gives a red color with iodine. It does not reduce Fehling's solution. *Diastase* and the *ptyalin* of saliva convert glycogen successively into a dextrin, maltose, and dextrose. Acids hydrolyze it to dextrose. Glycogen does not ferment with yeast.

399. Inulin, $(C_6H_{10}O_5)_x$, is a starch-like substance which occurs in the roots of the dandelion and chicory, in the tubers of the potato and dahlia, in certain lichens, and in other vegetable substances. Inulin is a white powder, composed of minute spheres; it is slightly soluble in cold water, and very soluble in hot water. An aqueous solution of inulin does not form a jelly, is not colored by iodine, is not fermentable, and is not affected by diastase. It is levorotatory, $[\alpha]_D = -36.6°$.

Inulin is slowly converted into levulose when boiled with water; the rate of transformation is greatly increased by the presence of an acid.

400. Cellulose, $(C_6H_{10}O_5)_x$, constitutes the framework of the vegetable kingdom. It occurs in nearly pure condition in certain plants, and probably in combination with other substances in the various kinds of wood. It can be separated from the compounds with which it is associated by treatment with various reagents. Cellulose is a comparatively stable substance and is insoluble in all simple solvents. It can be obtained by treating woody fiber, jute, flax, etc., successively, with chlorine and sodium hydroxide. A number of such treatments convert the substances present with the cellulose into soluble compounds. Cotton wool, which is comparatively pure cellulose, may be freed from impurities by extraction with alcohol, ether, and dilute acids and alkalies. The so-called "washed filter paper" is almost pure cellulose.

Chemical Properties and Uses.—Cellulose dissolves in *Schweitzer's reagent*, which is prepared by dissolving carefully washed precipitated copper hydroxide in ammonia. From this solution

it is precipitated in an amorphous condition by acids and salts. Advantage is taken of the effect of this reagent on cellulose in the preparation of waterproof paper. A sheet of paper left for a short time in contact with Schweitzer's reagent is superficially attacked, and when passed through rollers and dried is rendered impervious to water.

Cellulose dissolves in *concentrated sulphuric acid;* when the solution is diluted with water and boiled, soluble carbohydrates are formed, which vary in complexity from soluble celluloses and dextrins to dextrose, the final product of hydrolysis. When unsized paper is left in contact for a moment with sulphuric acid diluted with about one-fourth its volume of water, the surface of the paper is converted into a colloidal modification of cellulose called *amyloid.* After washing in water and dilute ammonia, the paper is found to have a smooth surface and to have been markedly toughened by the treatment. The so-called "parchment paper" is prepared in this way. Amyloid is colored blue by iodine; the reaction is used as a test for cellulose.

When cellulose is allowed to stand for some time with *hydrochloric acid,* which has been saturated with the gas below 0°, it is hydrolyzed and sugars are produced. Material prepared in this way from wood, after the removal of the acid, has been used as a cattle food in Germany.

Dilute solutions of the *alkalies* do not appreciably affect cellulose. With strong solutions, however, compounds with the alkali are formed, which decompose with water and form a hydrate of cellulose. These chemical changes are associated with a marked alteration in physical properties in the case of cellulose which is in the form of fibers. These changes take place in the manufacture of *mercerized cotton.* When cotton yarn is treated with a solution of sodium hydroxide which has the specific gravity 1.25, the fiber becomes rounded, swollen, and semitransparent, the interior cavity of the fiber almost disappears, and the yarn shrinks. The resulting product has a high luster and silky appearance. In mercerizing cotton, the yarn or cloth is held under tension in order to prevent shrinking during the treatment with alkali and the subsequent washing. As the result of mercerization cotton increases in weight on account of the change of cellulose to a hydrate, and can be dyed more readily.

401. *Cellulose Acetate.*—The presence of alcoholic hydroxyl groups in cellulose is shown by its behavior with reagents which react with such groups. When treated with acetic anhydride in the presence of a trace of concentrated sulphuric acid, cellulose is converted into a triacetate, $C_6H_7O_5(OC.CH_3)_3$, which finds important industrial application. Cellulose acetate is deposited from solution in the form of a tough film when the solvent evaporates; such films are used in photography, as an insulating coating for copper wire, and for other purposes. One form of artificial silk is made from cellulose acetate.

402. *Cellulose Nitrates.*—Cellulose reacts with nitric acid and forms nitrates, which are commonly called nitrocellulose. The number of acid radicals introduced is determined by the strength of acid used, the time during which the reacting substances are allowed to remain in contact, and the temperature. If cotton is treated with a mixture of concentrated nitric acid and concentrated sulphuric acid the hexanitrate $[C_{12}H_{14}O_4(NO_3)_6]_x$, is formed. The substance is called a hexanitrate and is considered as derived from a complex containing 12 carbon atoms, on account of the fact that a pentanitrate, $[C_{12}H_{15}O_5(NO_3)_5]_x$, is known.

Cellulose hexanitrate, called *guncotton*, is used in making smokeless powder. It is insoluble in water, alcohol, ether, and chloroform. It resembles in texture the cotton from which it is made. In the preparation of the explosive the nitrated cotton is converted into a pulp and molded into the desired shape by pressure. When exploded, guncotton is converted into carbon dioxide, carbon monoxide, nitrogen, hydrogen, and water vapor.

The nitrates of cellulose that contain less nitrogen than is present in guncotton are called *pyroxylin;* they are soluble in a mixture of alcohol and ether, the solubility decreasing with the increase in the percentage of nitrogen present. *Collodion* is a solution of pyroxylin in alcohol and ether. Large quantities of cellulose nitrate that contains about 11 per cent of nitrogen are prepared for making celluloid and lacquers. *Celluloid* is made by intimately mixing about 2 parts of pyroxylin and 1 part of camphor. "*Duco,*" which is extensively used as an automobile finish, is a solution of cellulose nitrate in a mixture of solvents to which pigments have been added; high-boiling liquids are also

present in order to bring about the formation of a smooth film when the solvent evaporates, and to render the resulting coating somewhat flexible.

403. *Artificial Silks: Rayon.*—The fact that cellulose can be changed into soluble compounds from which by simple treatment the cellulose can be recovered has made it possible to convert the carbohydrate into a variety of useful substances. Artificial silk has been made for a number of years by several processes based on this fact. In all of these methods a thick solution of the cellulose compound is forced through capillary tubes into a solution that converts the product into cellulose, which is obtained in the form of threads possessing a silky luster.

One form of artificial silk is made from a solution of cellulose in Schweitzer's reagent (**400**). Another form is made from soluble cellulose nitrate; in this case the threads formed as the result of the evaporation of the solvent are treated with a solution of sodium sulphide, which removes the nitrate radicals as the result of hydrolysis.

Rayon, which is the most important variety of artificial silk, is manufactured by a method based on the formation of a soluble compound of cellulose produced as the result of a reaction between the carbohydrate, sodium hydroxide, and carbon disulphide. A similar reaction takes place between alcohol and these reagents:

$$CS_2 + C_2H_5OH + NaOH = SC\begin{matrix}OC_2H_5\\SNa\end{matrix} + H_2O$$

The compound formed in this case is called sodium xanthate; it is a salt of the mono ethyl ester of dithiocarbonic acid. An analogous compound is formed from cellulose. It is prepared by allowing wood pulp or cotton linters to react for some time with a strong solution of sodium hydroxide, and then removing the excess of the solution by pressure. The sodium derivative formed in this way is next brought in contact with the vapor of carbon disulphide. The product is a viscous material which is called *viscose*. After filtration it is made into threads by forcing it into a dilute solution of an acid through tubes of different sizes, depending on the nature of the product desired. *Cellophane* is made in a similar way except that the viscose is forced through a narrow slot; the thin transparent sheets formed have found extensive use as a wrapping material.

Artificial silk is also made from cellulose acetate. Since the acetyl radicals are not removed after the threads have been formed, the silk has somewhat different properties from rayon, which is essentially pure cellulose. The term "rayon" is popularly applied to all forms of artificial silk.

404. Wood contains in addition to cellulose a substance called *lignin*, the composition of which has not been definitely established. It probably exists in wood in combination with cellulose as a compound which is called lignocellulose. A number of

lignocelluloses exist in different varieties of wood. The reactions of these substances indicate that the lignin which is present contains a free aldehyde group, as it reduces solutions of the oxide of copper and certain other metals. Lignin reacts with chlorine, caustic alkalies, bisulphites of the alkaline earths, and sulphur dioxide and forms compounds which are soluble in water.

These facts are made use of in the manufacture of *paper* from wood. In the process, the wood, which has been cut into small chips, is digested under pressure with a solution of sodium hydroxide or calcium bisulphite. This treatment frees the cellulose from lignin, resins, and other substances, and converts it into a pulp which, after disintegration and washing, is made into paper. This is done by passing a thin layer of the pulp through rolls, which squeeze out the water and convert the pulp into a compact sheet.

The presence of lignin in wood, straw, bran, etc., can be shown by certain characteristic color reactions. Such substances give a yellow color when treated with aniline hydrochloride, and a crimson color with phloroglucinol and hydrochloric acid. Lignin belongs to the class of compounds known as *pentosans*. They are so called because they yield a pentose on hydrolysis.

Wood contains from 8 to 10 per cent of a gum which is a mixture of complex carbohydrates. Wood gum yields xylose on hydrolysis and, like other substances which contain pentosans, is converted into furfural on boiling with hydrochloric acid. The formation of furfural, it will be recalled, is a test for a pentose (**385**).

405. Pectins.—The cellular tissue of many fruits contains cellulose associated with other substances of the nature of carbohydrates. When these pectocelluloses are treated with water, pectin passes into solution, from which it can be obtained by concentration and precipitation with alcohol. Lemons or apples are frequently used for this purpose. Pectin is a compound of complex structure which yields, on hydrolysis, arabinose, galactose, complex acids, and a small percentage of methyl alcohol and acetic acid.

Pectin is used in making fruit jellies because it forms a gel when a warm dilute solution of it (0.3 to 0.7 per cent) cools. This change takes place in the presence of a very small amount of

acid, equivalent to about 0.06 per cent of citric acid. If the material is boiled too long in making jelly the acids present cause a partial hydrolysis of the pectin present and the resulting solution does not gelatinize on cooling.

406. Gums.—The name *gum* is given to more or less complicated substances, most of which are mixtures, which contain complex acids and make sticky liquids when mixed with water. On hydrolysis the gum acids yield carbohydrates. Arabic acid occurs in nature as a mixture of the calcium, magnesium, and potassium salts in *gum arabic*. It is converted into arabinose on hydrolysis. *Agar-agar* is obtained in China from seaweed. It is a gum which gives galactose on hydrolysis. *Xylan* is a wood gum which is found in the bark of trees. It yields xylose when hydrolyzed by acids; when distilled with acids, the xylose formed is converted into furfural.

407. The Digestion and Metabolism of Carbohydrates.—Before a carbohydrate can be absorbed and utilized as food by the body it must be converted into a monosaccharide. Digestion consists in the hydrolysis of polysaccharides through the catalytic influence of enzymes, which are produced in the body. The process begins in the mouth. The saliva contains *ptyalin*, which brings about the conversion of starch into a soluble form and then into various dextrins, which decrease in complexity until a form is produced that gives no color with iodine; the dextrins are then hydrolyzed further to isomaltose, and finally to maltose. Ptyalin acts as a catalyst in hydrolyzing carbohydrates in weakly alkaline or neutral solution; its activity is destroyed by the presence of about 0.006 per cent of hydrochloric acid. The saliva contains disodium phosphate, which has an alkalinity equivalent to a 0.1 per cent solution of sodium carbonate. Dilution of the saliva with water up to seven times its volume increases the activity of ptyalin.

The saliva contains in addition to ptyalin maltase, which converts maltose to glucose, but this change takes place to only a slight degree in the mouth.

The gastric juice present in the stomach has an acidity equivalent to that of a 0.2 to 0.3 per cent solution of hydrochloric acid, and as the contents of the mouth are taken into the stomach neutralization of the alkali takes place and the digestion of carbohydrates ceases. When the partially digested material passes into the small intestine, hydrolysis of the starch continues under the influence of the enzyme *amylopsin*, which is present in the alkaline juice that flows from the pancreas into the small intestine. The lining of the latter secretes a juice that contains enzymes which convert disaccharides to monosaccharides. They are *sucrase*, which induces the hydrolysis of sucrose to glucose and fructose, *lactase* which converts lactose into glucose and galactose, and *maltase* which hydrolyzes maltose to glucose. The three

monosaccharides are then absorbed into the circulation system and pass to the liver, where they are converted into glycogen. The liver may contain as much as 10 per cent of its weight of glycogen.

Pure cellulose cannot be digested by man. There is present in green grasses, cereals, plants, and in the cell walls of certain seeds, such as peas and beans, a form of cellulose which is called hemicellulose because it is perhaps less highly condensed than the ordinary form of the carbohydrate. The hemicelluloses can be digested by herbivorous animals and to some extent by man. Since a considerable part of the carbohydrate undergoes fermentation with the result that methane is formed, the food value of the hemicellulose is lower than that of the other digestible polysaccharides. Normal cellulose and lignocellulose are digested by animals to the extent of from 30 to 60 per cent.

The changes in foods which follow digestion and absorption are a part of the process known as metabolism. This includes the changes which take place when the products of digestion are utilized in furnishing energy or in building up the substances of which the body is composed. In the metabolism of the carbohydrates the glycogen stored in the liver is converted into glucose, which passes into the blood at such a rate that the latter contains 0.1 per cent of the carbohydrate. The glucose is carried by the blood throughout the body to the cells, where oxidation and the liberation of energy take place as the result of the interacting of the carbohydrate with the oxyhemoglobin of the arterial blood, which furnishes the required oxygen.

If the amount of glucose supplied by the blood stream is not completely used to furnish energy, the carbohydrate is converted into glycogen in the muscle, where it is stored and drawn on as it is needed to furnish glucose. If the supply of carbohydrate food is greater than the amount that can be stored in the liver and the muscles, the excess is converted into fat.

408. Identification of Carbohydrates.—All carbohydrates give a marked color when treated with α-naphthol (**545**) and concentrated sulphuric acid (*Molisch carbohydrate reaction*). The test is carried out by treating about 5 milligrams of the substance with 10 drops of water and 2 drops of a 10 per cent solution of α-naphthol in chloroform; about 1 c.c. of pure concentrated sulphuric acid is then added to the mixture carefully so that two layers are formed. If a carbohydrate is present, a red ring will appear in a few seconds; on longer standing, or on shaking, a deep purple color will develop. When the solution is diluted with water, a dull-violet precipitate is formed, which is changed to a yellowish-brown color when treated with ammonia. As certain substances other than carbohydrates give colorations when treated with concentrated sulphuric acid, and as certain acids act like carbohydrates in the Molisch reaction, it is neces-

sary to make additional tests in case a substance responds to th reaction in the manner indicated. If the compound studie proves to be an acid when tested with litmus, or if it gives th characteristic color changes when treated with concentrate sulphuric acid alone, it is not a carbohydrate.

In identifying individual members of the class of carbohy drates, the osazones are usually prepared. Most carbohydrate do not melt sharply, as they undergo more or less decompositio when heated to their melting points. The action of a carbohy drate with Fehling's solution is also helpful in its identification

Pentoses are distinguished by their action when boiled wit phloroglucinol and hydrochloric acid; arabinose and xylose pro duce a bright-red color, which deepens in shade as the solution is boiled. Certain hexoses and polysaccharides give an orange color when heated with phloroglucinol and hydrochloric acid.

The soluble carbohydrates are most readily identified, in most cases, by determining their specific rotation.

Problems

1. Tabulate the following properties of dextrose, levulose, galactose, sucrose, lactose, maltose, raffinose, starch, glycogen, inulin, and cellulose: solubility in water; products formed on hydrolysis; fermentability; and action with Fehling's solution.

2. How could you determine quantitatively each component in the following mixtures: (*a*) starch and cane sugar, (*b*) starch and cellulose, (*c*) cane sugar and dextrose, (*d*) fructose, starch, and cellulose?

3. Write equations for reactions by which (*a*) an aldopentose may be converted into a ketopentose; (*b*) a ketohexose into an aldohexose; and (*c*) a triose into a tetrose.

4. How could you determine whether a film is one of cellulose, celluloid, or cellulose acetate?

5. How could you determine whether the sugar in an aqueous solution is sucrose, glucose, or lactose?

CHAPTER XVI

COMPOUNDS CONTAINING PHOSPHORUS, ARSENIC, SULPHUR, METALS

409. Phosphorus occurs in a large number of natural products of complex composition. It is an important constituent of certain proteins, which will be described later, and of the lecithins (**222**). Many of these compounds are esters of phosphoric acid in which the alcohol in combination with the acid is glycerol or a carbohydrate.

Many simple compounds of phosphorus are known, but they do not warrant detailed description here. *Esters of phosphoric acid and phosphorous acid* are formed when the halides of phosphorus are treated with an alcohol. It has already been pointed out that the interaction of these substances yields alkyl halides, a number of reactions taking place simultaneously. Typical reactions are those which take place between alcohol and phosphorus tribromide:

$$3C_2H_5OH + PBr_3 = 3C_2H_5Br + P(OH)_3$$

$$3C_2H_5OH + PBr_3 = 3HBr + P(OC_2H_5)_3$$

Under certain conditions compounds are obtained which contain halogen, such as $PBr_2(OC_2H_5)$. Esters can also be made by the action of the silver salts of the acids on alkyl iodides. Monoethyl phosphate can be prepared by treating alcohol with phosphoric acid; it is often called ethylphosphoric acid:

$$C_2H_5OH + H_3PO_4 = C_2H_5.H_2PO_4 + H_2O$$

The *phosphines* are compounds which are formed as the result of the replacement of one or more hydrogen atoms in phosphine, PH_3, by alkyl radicals. They resemble the amines in composition, and the methods employed to prepare them are, in general, analogous to those already described in the case of the derivatives of ammonia. The phosphines react with water and form bases,

which are weaker than the analogous ammonium compounds. Tetraethylphosphonium hydroxide, $(C_2H_5)_4P.OH$, is, however, a strong base.

The noticeable differences in chemical properties between the phosphines and amines are due to certain marked differences between nitrogen and phosphorus. The action of oxygen on the two elements furnishes a striking case; nitrogen and many of its compounds are inert, while phosphorus and certain of its derivatives are readily oxidized. This marked difference in activity between the two elements is met with in certain of their organic derivatives. Triethylamine, for example, is stable in the air, whereas triethylphosphine rapidly absorbs oxygen and forms an oxide, $(C_2H_5)_3PO$. Some phosphines oxidize so rapidly that they are spontaneously inflammable.

410. Arsenic forms primary, secondary, and tertiary arsines and quaternary bases. Tetraethylarsonium hydroxide, $(C_2H_5)_4As.OH$, is a base, which forms well-characterized salts. *Cacodyl* and its derivatives are arsenic compounds which had a marked influence on the development of the theories of organic chemistry. The compounds were investigated by Bunsen, who prepared cacodyl oxide, $[(CH_3)_2As]_2O$, by distilling arsenous oxide with potassium acetate. From the oxide, the chloride $(CH_3)_2AsCl$ was formed by the action of hydrochloric acid; the chloride yielded cacodyl, $[(CH_3)_2As]_2$, when treated with zinc. Other compounds such as the bromide, cyanide, etc., were prepared. All these contain the group $(CH_3)_2As$. It appeared from the results obtained by Bunsen and the investigations by Gay-Lussac on cyanogen, and Liebig and Wöhler on benzoyl derivatives that groups of atoms could pass intact from one compound to another. To such groups the name *radical* was applied. The first attempts to elucidate the structure of organic compounds were directed toward the discovery of the radicals which they contained.

Compounds Containing Sulphur

411. Many compounds of sulphur, which may be divided into a number of classes, are known. As sulphur resembles oxygen in many of its chemical properties, we might expect to

have a series of organic compounds containing sulphur analogous in composition to the oxygen derivatives of the hydrocarbons which have been described. A large number of such compounds are known, but only a few will be described here. The marked differences between sulphur and oxygen must be borne in mind in the study of the sulphur compounds. It will be remembered that sulphur is a more negative element than oxygen; the compound of oxygen and hydrogen, H_2O, is neutral, the analogous compound of sulphur, H_2S, is an acid. Further, sulphur forms well-characterized compounds in which the element exhibits valences of 4 and 6, while oxygen is bivalent; hydrogen sulphide can be oxidized to sulphuric acid. These striking differences between oxygen and sulphur lead to reactions in the case of organic compounds containing sulphur, which are not shown by the analogous oxygen derivatives.

412. Mercaptans may be considered as monosubstitution products of hydrogen sulphide, $C_2H_5.SH$, just as the alcohols are considered as derivatives of water, $C_2H_5.OH$. They are sometimes called thiols or thioalcohols. The name mercaptan was originally given to the members of this class on account of the fact that they form compounds with mercury. The name is derived from the Latin words *mercurium captans*. Ethyl mercaptan (ethanethiol) is a typical member of the class. It is prepared by methods which are analogous to those used in making alcohols:

$$C_2H_5Br + KSH = C_2H_5SH + KBr$$

$$C_2H_5SO_4K + KSH = C_2H_5SH + K_2SO_4$$

It can be prepared by passing hydrogen sulphide and the vapor of alcohol over heated thorium oxide. It is a liquid (b.p. 34.7°) which has an excessively disagreeable odor. It is said that it is possible to detect about 0.000000002 milligram of the substance. Ethyl mercaptan is difficultly soluble in water.

The hydrogen joined to sulphur in mercaptan can be replaced by metals; the compounds so formed are more stable than the alcoholates. The mercury compound has the formula $(C_2H_5S)_2Hg$.

Mercaptans can be oxidized readily on account of the possibility of increasing the valence of the sulphur atom present.

The resulting compounds are called sulphonic acids:

$$C_2H_5—S—H + 3O = C_2H_5—\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}—OH$$

413. Sulphides or thioethers are disubstitution products of hydrogen sulphide. They can be prepared by treating an alkyl halide or a salt of an alkylsulphuric acid with potassium sulphide:

$$2C_2H_5I + K_2S = (C_2H_5)_2S + 2KI$$
$$2C_2H_5SO_4K + K_2S = (C_2H_5)_2S + 2K_2SO_4$$

They are formed also by the action of a sodium salt of a mercaptan on an alkyl iodide:

$$C_2H_5I + C_2H_5SNa = (C_2H_5)_2S + NaI$$

The method last given is analogous to an important one used to prepare ethers. The sulphides are liquids, most of which have a very disagreeable odor. Allyl sulphide, $(CH_2{=}CH.CH_2)_2S$, is the chief constituent of the *oil of garlic*.

Like the mercaptans, the sulphides are readily oxidized. Nitric acid converts ethyl sulphide into *ethyl sulphoxide*, $(C_2H_5)_2SO$, which on more energetic oxidation yields a *sulphone*, $(C_2H_5)_2SO_2$.

The sulphides unite with alkyl iodides and form salts of the *sulphonium bases:*

$$(C_2H_5)_2S + C_2H_5I = (C_2H_5)_3S.I$$

The reaction is analogous to that by which salts of the ammonium bases are formed:

$$(C_2H_5)_3N + C_2H_5I = (C_2H_5)_4N.I$$

Like these, the sulphonium salts are converted into bases when shaken in aqueous solution with silver oxide:

$$(C_2H_5)_3SI + AgOH = (C_2H_5)_3S.OH + AgI$$

Triethylsulphonium hydroxide is a strong base; it absorbs carbon dioxide from the air and forms crystalline salts with acids.

414. One of the most important war gases was *β-, β′-dichlorodiethyl sulphide* $\begin{matrix}CH_2ClCH_2\\ \\ CH_2ClCH_2\end{matrix}\!\!>\!S$. It was prepared in a number of ways. The method used

by the Germans was analogous to the first method for making ethyl sulphide mentioned above. The steps involved are indicated by the following formulas:

$$C_2H_4 + HOCl \longrightarrow CH_2OH.CH_2Cl \xrightarrow{Na_2S} (CH_2OH.CH_2)_2S \xrightarrow{HCl} (CH_2Cl.CH_2)_2S$$

The method used by the French was the simplest chemically. It consisted in passing ethylene into a solution of sulphur dichloride in carbon tetrachloride, which was used as a diluent to prevent the action of the chloride on the product formed:

$$\begin{matrix} CH_2{=}CH_2 \\ CH_2{=}CH_2 \end{matrix} + \begin{matrix} Cl \\ Cl \end{matrix}\!\!>\!S = \begin{matrix} CH_2Cl.CH_2 \\ CH_2Cl.CH_2 \end{matrix}\!\!>\!S$$

In the methods used by the Americans and English ethylene was passed directly into sulphur monochloride:

$$\begin{matrix} CH_2{=}CH_2 \\ CH_2{=}CH_2 \end{matrix} + \begin{matrix} Cl \\ Cl \end{matrix}\!\!>\!S_2 = \begin{matrix} CH_2Cl.CH_2 \\ CH_2Cl.CH_2 \end{matrix}\!\!>\!S + S$$

β-, β'-Dichlorodiethyl sulphide was popularly known as "mustard gas" the name given to it when it was first used, on account of a fancied resemblance in the odor of the "gas" to that of mustard.

Mustard gas is a liquid which boils at 216°, freezes at 14°, and slowly hydrolyzes when in contact with water. It is the most toxic of the gases used in the war, and in addition is highly vesicant, as it produces painful "burns" at a high dilution.

415. Sulphonal, which is used as a soporific, is a disulphone derived from mercaptan. When a mixture of acetone and mercaptan is treated with hydrochloric acid, condensation takes place according to the equation:

$$(CH_3)_2CO + 2C_2H_5SH = (CH_3)_2C(SC_2H_5)_2 + H_2O$$

The substance so formed yields on oxidation a disulphone, which is sulphonal:

$$(CH_3)_2C(SC_2H_5)_2 + 4O = (CH_3)_2C(SO_2C_2H_5)_2$$

Trional is made in an analogous manner from methyl -ethyl ketone; it has the structure $\begin{matrix} CH_3 \\ C_2H_5 \end{matrix}\!\!>\!C(SO_2C_2H_5)_2$. *Tetronal*, which has a similar constitution, contains four ethyl groups.

416. Thioacids can be prepared by the action of potassium hydrosulphide on acid chlorides:

$$CH_3COCl + KSH = CH_3COSH + KCl$$

or by distilling acetic acid with phosphorus pentasulphide.

The thioacids are liquids which have a disagreeable odor. The salts of these acids which contain a heavy metal are decomposed when heated in aqueous solution, and sulphides of the metals are precipitated.

417. When thioacetic acid is treated with ethyl alcohol, ethyl acetate and hydrogen sulphide are formed:

$$CH_3COSH + C_2H_5OH = CH_3COOC_2H_5 + H_2S$$

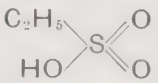
On the other hand, when acetic acid is treated with mercaptan, an ester of thioacetic acid is formed:

$$CH_3COOH + C_2H_5SH = CH_3COSC_2H_5 + H_2O$$

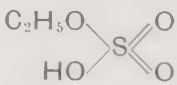
It appears highly probable from these facts that when an organic acid and a primary alcohol react and form an ester, the hydroxyl group involved is furnished by the acid and the hydrogen by the alcohol. If this is true, ester formation differs materially from salt formation in which the hydroxyl group is furnished by the base.

418. Thioaldehydes and thioketones are not known in the pure condition. When hydrogen sulphide is passed into an aqueous solution of aldehyde, an oil is formed which appears to be a mixture of thioaldehyde and its polymer $(CH_3.CHS)_3$. When acetone is treated in the same way, thioacetone, $CH_3.CS.CH_3$, is probably formed along with other substances.

419. Sulphonic acids are compounds which contain the SO_3H group, in which the organic radical present is in combination with sulphur. The relation between the structure of ethanesulphonic acid and acid ethyl sulphate is shown by the following formulas:



Sulphonic acid



Acid sulphate

It has already been stated that the higher paraffins are converted in part into sulphonic acids when boiled with concentrated

sulphuric acid for a number of days. The reaction between the acid and a hydrocarbon involves the elimination of water:

$$C_7H_{16} + H_2SO_4 = C_7H_{15}SO_3H + H_2O$$

As this method is not a practical one, the sulphonic acids are usually prepared by the action of sulphites on alkyl halides:

$$C_2H_5I + K_2SO_3 = C_2H_5SO_3K + KI$$

While the saturated hydrocarbons are but slowly affected by sulphuric acid or sulphur trioxide, their derivatives react more energetically with these reagents. When alcohol, for example, is treated with sulphur trioxide, sulphonation takes place, *i.e.*, the alcohol is converted into a sulphonic acid:

$$CH_3.CH_2OH + SO_3 = HSO_3CH_2.CH_2OH$$

The compound formed is β-hydroxy-ethanesulphonic acid; it is usually called *isethionic acid*. *Ethionic acid*, which is the acid sulphate of isethionic acid, $HSO_3.CH_2.CH_2.SO_4H$, is formed at the same time. Both acids are formed in small quantity in the preparation of ether from alcohol and sulphuric acid.

420. Taurine, β-amino-ethanesulphonic acid, is found in combination with other substances in the bile of many animals. It can be prepared from isethionic acid by the steps indicated by the following formulas:

$$\begin{array}{l} CH_2OH \\ | \\ CH_2SO_2OH \end{array} \xrightarrow{PCl_5} \begin{array}{l} CH_2Cl \\ | \\ CH_2SO_2Cl \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2Cl \\ | \\ CH_2SO_2OH \end{array} \xrightarrow{NH_3} \begin{array}{l} CH_2NH_2 \\ | \\ CH_2SO_2OH \end{array}$$

Sulphoacetic Acid.—Acetic acid can be sulphonated:

$$CH_3.COOH + SO_3 = CH_2\begin{array}{l}\diagup SO_3H \\ \diagdown COOH\end{array}$$

The acid can also be prepared from chloroacetic acid and potassium sulphite:

$$CH_2Cl.COOK + K_2SO_3 = CH_2\begin{array}{l}\diagup SO_3K \\ \diagdown COOK\end{array} + KCl$$

421. Thiocyanic acid, HCNS, often called sulphocyanic acid, resembles cyanic acid in properties. It can be obtained as a volatile, pungent liquid, which rapidly polymerizes to a solid. *Potassium thiocyanate* is formed by heating a solution of potassium cyanide with sulphur:

$$KCN + S = KCNS$$

Ferric thiocyanate, $Fe(CNS)_3$, which has a characteristic blood-red color, is formed when a soluble thiocyanate is added to a ferric salt. The reaction furnishes a convenient test for ferric salts or a thiocyanate. The so-called "Pharaoh's serpents" are made from *mercuric thiocyanate*. *Ammonium thiocyanate*, NH_4CNS, is converted by heat into *thiourea*, $SC(NH_2)_2$, the reactions of which are analogous to those of urea, $CO(NH_2)_2$.

Esters of thiocyanic acid are obtained by the action of alkyl iodides on the salts of the acid:

$$KSCN + C_2H_5I = C_2H_5SCN + KI$$

As these esters yield mercaptans on reduction, it is assumed that the alkyl radicals which they contain are linked to sulphur, $C_2H_5—S—C{\equiv}N$.

When heated, the alkyl thiocyanates are changed into the isomeric *isothiocyanates:*

$$R—S—C{\equiv}N \longrightarrow R—N{=}C{=}S$$

The esters of this structure are also called *mustard oils*, after *allyl isothiocyanate*, $CH_2{=}CH.CH_2.NCS$, the constituent of mustard which gives it its characteristic odor and taste. The radicals in isothiocyanates are considered to be joined to nitrogen on account of the fact that these esters yield amines on hydrolysis.

422. The alkyl thiocarbonates are derived from dithiocarbonic acid, HO.CS.SH, or trithiocarbonic acid, HS.CS.SH. Carbon disulphide reacts with sulphides to form salts analogous to the carbonates, which are formed by the union of carbon dioxide and metallic oxides:

$$CS_2 + CaS = CaCS_3$$

$$CO_2 + CaO = CaCO_3$$

Esters of trithiocarbonic acid are formed from inorganic salts of the acid in the usual way:

$$K_2CS_3 + 2CH_3SO_4K = (CH_3)_2CS_3 + 2K_2SO_4$$

The more important thio derivatives of carbonic acid are those which contain two sulphur atoms. The salts of the *xanthic acids* are formed by shaking together carbon disulphide, an

alcohol, and an alkali. Potassium xanthate is prepared in this way from alcohol:

$$CS_2 + C_2H_5OH + KOH = SC\begin{matrix}OC_2H_5\\SK\end{matrix} + H_2O$$

Traces of carbon disulphide are detected by means of this reaction. The potassium xanthate formed produces a characteristic yellow precipitate when treated with a solution of a copper salt.

Organometallic Compounds

423. Many elements form compounds in which alkyl groups are in combination with the element. The amines NR_3, phosphines PR_3, sulphides SR_2, ethers OR_2 have already been described. Compounds of this type which contain the metallic elements, such as zinc, tin, lead, aluminium, mercury, etc., are known as organometallic compounds or as metallic alkides. They were first described by Frankland, who pointed out clearly in 1852 that the metals and other elements differed from one another in their ability to hold in combination organic radicals; some could unite with two radicals, some with three, and some with four. From these facts he was led to propose the doctrine of valency. The organometallic compounds have been of great service in determining the valence of metals on account of the fact that they may be vaporized without decomposition. The student will recall the fact that the molecular weight, and consequently the formula of a compound, can be calculated from its percentage composition and the density of its vapor.

On account of their value in synthetic organic chemistry, certain metallic alkides which contain zinc and magnesium will be described briefly.

424. Diethylzinc, $(C_2H_5)_2Zn$, which is also called zinc ethyl, is prepared from zinc and ethyl iodide. When the two substances are heated together addition takes place slowly:

$$C_2H_5I + Zn = Zn\begin{matrix}C_2H_5\\I\end{matrix}$$

The reaction takes place more rapidly in the presence of a small quantity of ethyl acetate or methyl cyanide, or when the zinc-

copper couple is used. Ethylzinc iodide is a colorless, crystalline solid, which is decomposed by water and reacts with many compounds that contain a halogen or oxygen. The decomposition in the case of water is represented by the equation:

$$C_2H_5.Zn.I + HOH = C_2H_6 + Zn.OH.I$$

When heated, ethylzinc iodide decomposes, and zinc ethyl is formed:

$$2C_2H_5.ZnI = Zn(C_2H_5)_2 + ZnI_2$$

Diethylzinc is a colorless liquid, which boils at 118° and fumes in the air. It takes fire spontaneously, and burns with a luminous green-edged flame.

The zinc alkyls were formerly much used in effecting syntheses, but they have been largely replaced for this purpose by the more stable alkyl derivatives of magnesium, which can be prepared more readily.

425. Magnesium compounds which contain alkyl radicals can be readily prepared by the action of the metal on alkyl halides:

$$C_2H_5I + Mg = Mg\begin{matrix}C_2H_5\\ I\end{matrix}$$

The reaction is usually brought about by adding magnesium in the form of powder or ribbon to a solution of the alkyl halide in dry ether. Reaction takes place more promptly if a trace of iodine is added to the mixture. The alkylmagnesium halides, so prepared, are solids that are soluble in ether, with which they form crystalline molecular compounds of the type $RMgHl\text{-}2(C_2H_5)_2O$. The solutions formed in the way indicated are much used in effecting the preparation of compounds of various classes by what is known as the Grignard reaction. The applications of alkylmagnesium halides to the preparation of hydrocarbons (**21**), primary alcohols, secondary alcohols and tertiary alcohols (**85**), acids (**113**) and ketones (**202**) have been described.

426. Tetraethyllead, $(C_2H_5)_4Pb$, is used in certain varieties of gasoline because it prevents "knocking" in automobile engines. It is prepared from ethyl chloride and an alloy of sodium and lead. "Ethyl gas" contains ethylene bromide in addition to tetraethyl-

lead; the halogen compound takes part in the removal of lead from the cylinder in the form of lead bromide.

Problems

1. How could you (*a*) distinguish C_4H_9SH from $(C_2H_5)_2S$; (*b*) show that taurine contains an amino group; (*c*) show the presence of a trace of CS_2 in benzene?

2. Write equations using graphic formulas by which the following may be made by means of the Grignard reaction: (*a*) $CH_3.C_3H_7CHCOOH$, (*b*) $(C_2H_5)_3COH$, (*c*) hexene-1, (*d*) $(CH_3)_2CHCOOH$, (*e*) C_4H_{10}, (*f*) $(CH_3)_2$-$CH.CH_2.CH(CH_3)_2$.

CHAPTER XVII

THE IDENTIFICATION OF ORGANIC COMPOUNDS AND THE DETERMINATION OF THEIR STRUCTURE

427. As the different classes of organic compounds have been described in previous chapters, emphasis has been placed upon those reactions of the various substances which are of particular value in identifying the characteristic groups that they contain. The reactions which take place between oxygen compounds and phosphorus pentachloride, for example, have been described in detail, and it has been pointed out that the composition of the products formed gives, in most cases, definite information as to the way in which the oxygen is linked to other atoms in the molecule. By means of this reagent it is possible to determine whether the oxygen compound is an ether, ketone, or hydroxyl derivative. A number of qualitative tests have also been described, such as those for carbohydrates, aldehydes, esters, etc. The plan of this chapter is to bring together these various tests and reactions, and show by a few examples how they may be used in identifying a substance which has already been described, and in determining the structure of new substances.

The student has already seen, in a number of cases, how the structure of a substance is derived from a study of its reactions. But in most of the cases which have been described, the structural formula has been given, and it has been shown that the reactions of the substance are in accord with the formula. It is easier to see the relations between structure and reactions from this point of view, and consequently this method has been adopted up to the present. In determining the structure of a new substance, the investigator has before him only the results of analyses and molecular-weight determinations of the new compound and the derivatives which he has prepared from it. From these data he arrives at the structural formula.

An attempt will be made to show how such conclusions are reached.

The study of the transformations of organic compounds from this point of view is of the greatest importance. The study at this time furnishes a very practical review of many facts already presented, and gives the student an opportunity to use the facts which he has learned. The problems given at the end of the chapter should be solved, after the methods used in their solution, which are about to be described, have been studied. The student will in this way gain power in attacking organic problems, and will see more clearly the practical significance of the facts he has learned.

The reactions of the organic compounds treated up to this point, which are of particular value from the point of view of identification or the determination of structure, will be briefly reviewed. In the case of a number of classes certain of these reactions and tests have already been summarized. In such cases references to the sections which contain the summaries will be given, in order to avoid undue repetition. These references should be reread at this time along with what is now given. The attempt will not be made to include all the classes which have been mentioned, nor to emphasize exceptions to the general reactions discussed. It is the opinion of the author that in the study of the elements of organic chemistry, the attention of the student should be directed to general principles, and that the consideration of anomalous reactions and exceptions to the principles should be left to the detailed study of the specialist.

428. *Unsaturated Compounds.*—Read the section on the identification of hydrocarbons of the ethylene series (**44**), and of compounds containing a triple bond (**59**). If a substance of unknown structure forms a compound by the direct addition of two halogen atoms, the conclusion can be drawn that it is an unsaturated compound. In most cases it can be assumed that the substance contains a double bond between two carbon atoms. Thus, if a substance of the composition C_3H_6O is converted by bromine into one of the composition $C_3H_6Br_2O$, it is probable that it contains a double bond. If four atoms of halogen are added, the compound contains either two double bonds or one triple bond. If the compound gives a metallic derivative with an

ammoniacal solution of cuprous chloride, it contains a triple bond. If this test is negative, other means must be employed to determine the nature of the unsaturation, as metallic compounds are formed only by substances which contain the $C \equiv CH$ group. Oxidation is frequently used for this purpose, as unsaturated compounds generally break at the double or triple bond when oxidized. The study of the compounds formed on oxidation is often of material help in determining the structure of unsaturated compounds.

Hydrocarbons.—Read the section on the detection of the paraffins (**32**). In order to identify a substance as a hydrocarbon it is necessary to apply all the tests for oxygen compounds. If these yield negative results and no elements other than carbon and hydrogen are found to be present, the conclusion can be drawn that the compound is a hydrocarbon.

Acids.—Read the paragraph on the properties of acids of analytical significance (**126**). Acids (R.COOH) neutralize alkalies and liberate carbon dioxide from carbonates. In testing for an acid it is better to use a carbonate, as some esters are rapidly saponified by alkalies in the cold.

In determining the structure of an acid, the composition of its salt is often studied. Thus, if an acid of the composition $C_5H_{10}O_2$ yields salt $C_5H_9NaO_2$, it contains one carboxyl group, as one hydrogen atom is replaced by one sodium atom; if the acid $C_4H_6O_6$ gives the salt $C_4H_4Na_2O_6$, it is dicarboxylic, as two hydrogen atoms are replaced by two sodium atoms.

Phosphorus pentachloride replaces hydroxyl groups by chlorine. The action of this reagent on a substance of unknown structure is often studied. If a carboxyl group is present, the hydroxyl group which it contains is replaced by chlorine; the substance loses one hydrogen atom and one oxygen atom, and gains one chlorine atom. Thus if the compound $C_5H_{10}O_2$ is converted into the compound C_5H_9ClO, it is said to contain a hydroxyl group.

Alcohols.—Read the section on the reactions of alcohols (**87**). Alcohols react with acetyl chloride and form esters and hydrogen chloride, which is readily recognized by its fuming with moist air or with ammonia. Acetic anhydride also con-

verts alcohols into esters, many of which have characteristic odors. Distillation of an alcohol with strong hydrobromic acid yields the corresponding bromide.

The presence of an alcoholic hydroxyl group is usually shown qualitatively by the application of the tests just described. The same reagents are employed in the quantitative study of alcohols. In the replacement of a hydrogen atom by an acetyl radical, CH_3CO, the compound loses one hydrogen atom and gains C_2H_3O. The ester differs in composition from the alcohol by C_2H_2O. Thus, if when the compound C_3H_8O is treated with acetyl chloride or acetic anhydride it is converted into one of the composition $C_5H_{10}O_2$, the conclusion is drawn that it contains one alcoholic hydroxyl group. If by the action of these reagents a substance of the formula $C_3H_8O_2$ yields one of the formula $C_7H_{12}O_4$, the former contains two such groups, as the ester differs in composition from the alcohol by $2(C_2H_2O)$.

The change in composition effected by the halides of phosphorus is the same as that described above under acids. For each hydroxyl group present there is a loss of one hydrogen and one oxygen, and a gain of one halogen atom.

Methods which can be used to determine qualitatively whether an alcohol is primary, secondary, or tertiary are described in the section on tertiary alcohols (**78**). In certain cases more complicated methods than those described must be used. The study of the products formed on oxidation gives definite information as to the nature of an alcohol. Oxidation of a primary alcohol, which contains the group CH_2OH, leads to the formation of an acid. In the change of CH_2OH to COOH, the compound loses two hydrogen atoms and gains one oxygen atom. If the compound $C_4H_{10}O$ yields the compound $C_4H_8O_2$ on oxidation, it contains a primary alcoholic group and the substances have the structural formulas $CH_3CH_2CH_2CH_2OH$ and $CH_3CH_2CH_2$-COOH, respectively.

Ketones are formed from secondary alcohols by oxidation, the CHOH group being converted into C=O. In this case the change consists in the removal of two hydrogen atoms. If a compound has, for example, the formula $C_4H_{10}O$ and its oxidation product the formula C_4H_8O, the former is a secondary

alcohol. The relation between the structures of the two substances in this case is shown by the formulas

Oxidation converts a tertiary alcohol into compounds which contain a smaller number of carbon atoms than the alcohol. It is clear from what has been said how the composition of the products of oxidation of an alcohol serves to determine its nature. If an alcohol of the formula $C_4H_{10}O$ gives a compound of the composition $C_4H_8O_2$, it is a primary alcohol; if the oxidation product has the formula C_4H_8O, the alcohol is secondary; and if it yields two compounds, it has the tertiary structure.

Aldehydes.—The properties of aldehydes which are of special value in their identification are described in Sec. **191.** Aldehydes on oxidation yield acids, the CHO group being converted into carboxyl, COOH. The aldehydes differ in composition from the acids by one oxygen atom. Phosphorus pentachloride replaces one oxygen atom by two chlorine atoms. Acid potassium sulphite adds directly to an aldehyde. Hydroxylamine forms oximes; the aldehyde C_2H_4O gives the oxime C_2H_5NO, the change in composition resulting in the addition of one hydrogen and one nitrogen atom to the molecule.

Ketones.—Read the section on the properties of ketones (**205**). Substances of this class show many of the reactions of aldehydes. They may be distinguished from the latter by an examination of the products formed on oxidation. The ketones are decomposed by oxidizing agents into substances containing a smaller number of carbon atoms.

Ethers.—The properties of ethers are described in Sec. **150**. When an ether is heated with concentrated hydriodic acid, the alkyl groups linked to oxygen are converted into alkyl iodides. If a substance of the composition $C_{10}H_{22}O$ yields the iodide $C_5H_{11}I$ when boiled with hydriodic acid, the conclusion can be drawn that it contains a $C_5H_{11}O$ group.

Esters.—The methods for the qualitative identification of esters are described in Sec. **178.** Esters yield on hydrolysis with sodium hydroxide an alcohol and the sodium salt of an acid. If the compound $C_5H_{16}O_2$ is converted by a solution of sodium

hydroxide into the salt $C_5H_9NaO_2$ and the alcohol C_3H_8O, it can be concluded that it is a propyl ester of a valeric acid, C_4H_9COOH.

Anhydrides.—The important characteristic reaction of substances of this class are described in Sec. **158.** Sodium hydroxide converts anhydrides into salts. Esters also yield salts, but with these compounds an alcohol is formed at the same time. If the compound $C_8H_{14}O_3$ is converted by sodium hydroxide into a salt of the composition $C_4H_7NaO_2$, it is evident that the original compound is the anhydride of the acid $C_3H_7.COOH$.

Amines.—The tests for amines and ammonium salts are given in Sec. **217.** Amines form salts by direct addition to acids. If the substance C_3H_9N, for example, forms the compound $C_3H_{10}ClN$, it is probably an amine or a related basic compound such as a hydrazine, amidine, etc.

Amides.—Read the section on the identification of amides (**235**). In the conversion of an amide into a sodium salt of the corresponding acid, the amide loses one nitrogen and two hydrogen and gains one sodium and one oxygen atom. If a reaction takes place according to the equation

$$C_3H_7NO + NaOH = C_3H_5NaO_2 + NH_3$$

it can be interpreted as follows:

$$C_2H_5CONH_2 + NaOH = C_2H_5COONa + NH_3$$

In hydrolysis with acids the change in composition is brought about as the result of the loss of one hydrogen atom and one nitrogen atom, and a gain of one oxygen atom:

$$C_3H_7NO + H_2O = C_3H_6O_2 + NH_3$$
$$C_2H_5CONH_2 + H_2O = C_2H_5COOH + NH_3$$

Esters of nitrous and nitric acids give alcohols and salts of these acids when hydrolyzed by a base.

Sulphur Compounds.—Mercaptans form salts by the replacement of one hydrogen atom by metals. *Sulphides* do not form salts; they yield sulphoxides and sulphones on oxidation. *Sulphates* of amines give a precipitate of barium sulphate with barium chloride. The alkyl sulphates yield inorganic sulphates on hydrolysis. The *sulphonic acids* are not hydrolyzed by bases.

Halogen Compounds.—The identification of *alkyl halides* is discussed in Sec. **261,** and of *acyl halides* in Sec. **287.** The halogen in both classes of compounds may be replaced by the hydroxyl group, the compound losing the halogen atom and gaining one hydrogen and one oxygen atom. If the substance of the composition C_4H_9Cl is converted into one of the composition $C_4H_{10}O$ when heated for a long time at a high temperature with water or a solution of potassium hydroxide, it can be concluded that the former is an alkyl halide. An analogous change takes place more rapidly at a low temperature in the case of acyl halides.

The Identification of Unknown Substances

429. A number of examples will now be given to illustrate how the principles outlined above may be used in identifying substances which have been previously described.

The substance to be identified must be in a pure condition in order that its physical properties may be accurately determined and the conclusions drawn from its reactions may be trustworthy. If the substance does not show the characteristics of a pure compound, it must be purified by the methods already outlined (**9, 10**). A qualitative analysis is next made to determine what elements are present. The action of the compound is then studied with water, concentrated sulphuric acid, a hot and a cold solution of sodium hydroxide, dilute hydrochloric acid, acetyl chloride, bromine, sodium carbonate, phenylhydrazine, and Schiff's reagent. The carbohydrate test (**408**) should be applied, and if the compound contains sulphur the reactions given above under sulphur compounds should be studied. It is sometimes advisable and is often necessary to use other reactions than those just mentioned. A few examples will now be given.

I. (1) The substance contains nitrogen and sulphur.

(2) It is an odorless, colorless solid which is soluble in water.

(3) Sodium hydroxide precipitates an oil, which is soluble in dilute acids.

(4) Barium chloride gives a precipitate, insoluble in acids.

(5) The substance liberated by (3) does not react with acetyl chloride.

Observation (1) suggests the determination of the class of nitrogen compounds to which the substance belongs. Observation (2) indicates that it may be a salt of an amine—a conclusion confirmed by (3). These results, together with the fact that the compound contains sulphur, suggests test (4), which indicates a sulphate. The test applied to the oil obtained in (3) to determine the class to which the amine belongs (5), indicates that the original substance contains a tertiary amine. The study of the compound leads, then, to the conclusion that it is a sulphate of a tertiary amine. The identification is completed by the determination of physical properties. The boiling point of the free amine was determined in this case to be 157°, and its specific gravity to be 0.76. An examination of the physical constants of the known tertiary amines showed that the values obtained in this case were those which have been found for tripropylamine. The compound identified is, therefore, the sulphate of tripropylamine.

II. (1) Qualitative analysis showed that no elements other than carbon, hydrogen, and oxygen were present.

(2) The substance liberated carbon dioxide from sodium carbonate.

(3) It reacted with acetyl chloride, and hydrogen chloride was evolved.

(4) Tests for aldehydes, ketones, esters, anhydrides, and ethers gave negative results.

Observation (2) indicates that the substance is an acid and (3) that it contains an alcoholic hydroxyl group. These observations together with (4) lead to the conclusion that the substance is a hydroxy acid. The substance was found to melt at 79°. This is an indication that the substance is glycolic acid, which melts at this temperature. Glycolic acid is converted by nitric acid into oxalic acid which can be readily identified. The substance being studied was treated with nitric acid under the conditions used to bring about this transformation, and oxalic acid was obtained. The identification of the substance as glycolic acid was thus accomplished.

III. (1) Qualitative analysis showed that no elements other than carbon, hydrogen, or oxygen were present.

(2) The substance dissolved in cold concentrated sulphuric acid, and was precipitated on dilution.

(3) It was insoluble in cold dilute sodium hydroxide, but dissolved when heated.

(4) Tests for aldehydes, ketones, and anhydrides gave negative results.

Observation (2) indicates that the compound contains oxygen and that it may be an ester, an ether, or an anhydride. The conclusion is drawn from (3) and (4) that it is an ester. The boiling point of the compound was found to be 102°. As a number of esters boil at temperatures near 102°, the compound was identified by determining the boiling point of the alcohol formed when it was saponified. This was found to be 97°, which is the boiling point of propyl alcohol. As propyl acetate boils at 102°, the identification of the compound as this substance may be considered as satisfactory.

IV. (1) The substance contains chlorine.

(2) It is lighter than water and is not affected by it.

(3) It is insoluble in concentrated sulphuric acid.

(4) It does not react with acetyl chloride, bromine, sodium hydroxide, or other reagents used in the tests.

Observation (2) indicates that the compound is a monohalogen derivative of a hydrocarbon, as chlorine compounds which contain more than one halogen atom are heavier than water. Observations (3) and (4) indicate that no oxygen is present, and that the substance is saturated. The boiling point of the substance was found to be 46°, and its specific gravity 0.89. As these are the constants for propyl chloride, the conclusion is drawn that the substance is this compound.

V. (1) The substance contains no elements other than carbon, hydrogen, and oxygen.

(2) Sodium liberates hydrogen.

(3) Acetyl chloride reacts with evolution of hydrogen chloride.

(4) Tests for aldehydes, acids, ketones, etc., give negative results.

(5) An aqueous solution of the substance decolorizes potassium permanganate.

Observation (2) indicates the presence of a hydroxyl group, which is shown by (3) to be alcoholic. The compound is unsatu-

rated (5), and probably contains no other group (4) than an alcoholic hydroxyl group. The boiling point of the substance was found to be 97°. Allyl alcohol boils at this temperature. The unknown substance was treated with bromine and a bromide was obtained which boils at 214°. As allyl alcohol forms a dibromide which boils at this point, the identification of the unknown substance as this alcohol is satisfactory.

Separation of Mixtures

430. The methods which have been outlined and illustrated above can be applied only to pure compounds. When a mixture is to be studied the problem becomes more complicated. It is often impossible to separate readily the constituents of a mixture by distillation or crystallization, and other methods based on the difference in chemical properties or solubilities of the constituents of the mixture are often used.

A mixture which is to be examined is broken down into its constituents as far as possible by treating it with various substances, which either dissolve certain constituents of the mixture as such or convert them into soluble compounds. In effecting such solutions the following substances are frequently used: Water, which removes from the mixture substances soluble in water; a solution of hydrochloric acid, which removes basic substances insoluble in water; a solution of sodium hydroxide, which dissolves acids insoluble in water; concentrated sulphuric acid, which separates many oxygen compounds from hydrocarbons and certain halogen derivatives; and organic solvents which, in certain cases, may dissolve certain constituents of the mixture and not others.

The separation of mixtures into their constituents is illustrated by the following simple cases. The first mixture contained palmitic acid and paraffin. Neither water nor hydrochloric acid affected the mixture. When shaken with an alkali, a part dissolved which was precipitated on adding acid to the alkaline solution. The residue was unaffected by concentrated sulphuric acid. A second mixture, which contained acetone, kerosene, and amyl acetate, was first treated with water which removed acetone. Cold concentrated sulphuric acid separated

the ester from the mixture of hydrocarbons. On dilution of the solution in acid, care being taken to prevent a rise in temperature, the ester was precipitated.

It is evident that if a mixture contains two or more constituents which are members of the same class of compounds or are soluble in the same reagents, separation cannot be effected in the way outlined. In such cases fractional distillation or crystallization must be resorted to. A thorough knowledge of the properties of compounds is of great value in the examination of mixtures and is of service in the purification of compounds. The purification of ethyl bromide prepared from potassium bromide, alcohol, and sulphuric acid, is an example. The bromide prepared in this way may contain ether, which is separated with difficulty from the halide by distillation. When the mixture is shaken with concentrated sulphuric acid, the ether dissolves and the bromide is unaffected. In effecting the separation of compounds it is often necessary to convert them into other substances. Thus, acetone can be separated from many other substances which are soluble in water by converting it into the difficultly soluble addition product with sodium hydrogen sulphite.

Determination of Structure

431. It will now be shown how the structure of a compound may be determined by a study of the composition of the compound itself and of the substances prepared from it as the result of the action of certain reagents. The following examples will illustrate the method used.

I. (1) An analysis and a determination of the molecular weight showed that the composition of the substance was that represented by the formula $C_5H_{10}O_3$.

(2) When treated with a solution of sodium hydroxide a salt of the formula $C_4H_7NaO_3$ and methyl alcohol were obtained.

(3) The acid $C_4H_8O_3$ obtained from the salt $C_4H_7NaO_3$ yielded ethyl iodide when boiled with a concentrated solution of hydriodic acid.

It is seen from the reaction which gave the results in (2)

$$C_5H_{10}O_3 + NaOH = C_4H_7NaO_3 + CH_3OH$$

that the change consists in the replacement of CH_3 by Na. This together with the formation of methyl alcohol shows clearly that the compound is a methyl ester. The formation of ethyl iodide (3) shows that the acid $C_4H_8O_3$ contains a C_2H_5O group and is an ether. These facts lead to the conclusion that the structure of the acid is that represented by the formula C_2H_5O-CH_2.COOH and considered with observation (2) to the view that the substance investigated has the formula $C_2H_5O.CH_2.COOCH_3$.

II. (1) Analysis and a molecular weight determination of a substance led to the formula $C_3H_4Cl_2O$.

(2) When treated with cold water an acid of the composition $C_3H_5ClO_2$ was formed.

(3) This acid was converted by shaking with silver hydroxide into the silver salt of an acid of the formula $C_3H_6O_3$.

(4) The compound $C_3H_6O_3$ yielded on oxidation an acid, $C_3H_4O_3$.

Observation (2) shows that when the compound was treated with water one chlorine atom was replaced by one hydrogen and one oxygen atom; the substance is, therefore, the chloride of an acid. Silver hydroxide (3) brought about a similar replacement of chlorine by hydroxyl; in this case the hydroxyl group introduced is that of an alcohol. The conclusion to be drawn from these two observations is that the compound $C_3H_6O_3$ is a hydroxy-monocarboxylic acid $C_2H_4OH.COOH$. Two structures can be assigned to the substance which are in accord with this view, namely, $CH_2OH.CH_2.COOH$ and $CH_3.CHOH.COOH$. Observation (4) serves to determine which of these two is correct. In the oxidation of the substance $C_3H_6O_3$, two hydrogen atoms are removed from the compound; the substance contains, therefore, a secondary alcohol group, and its formula is consequently that of α-hydroxy-propionic acid. The structural formulas for the substances involved in the changes described are $CH_3.CHCl.COCl$, $CH_3.CHCl.COOH$, $CH_3.CHOH.COOH$, and $CH_3CO.COOH$.

III. (1) An analysis and a molecular weight determination led to the formula $C_4H_7NO_3$.

(2) A cold solution of potassium hydroxide reacted to form the salt $C_4H_6KNO_3$.

(3) When boiled with potassium hydroxide, ammonia was set free and the salt $C_4H_4K_2O_4$ was formed.

(4) The acid prepared from the salt $C_4H_4O_4K_2$ lost carbon dioxide when heated.

Observation (2) shows that the compound is a monocarboxylic acid, as one hydrogen atom was replaced by one of potassium when the compound was treated with a cold solution of potassium hydroxide. The hot solution of the alkali brought about the replacement of NH_2 by OK; the substance is, therefore, an amide. These observations lead to the conclusion that the original substance contains a COOH group and a $CONH_2$ group. The formula is accordingly $C_2H_4.CONH_2.COOH$. Two compounds of this formula are possible, namely

$$\begin{matrix} CH_2.CONH_2 \\ | \\ CH_2.COOH \end{matrix} \quad \text{and} \quad CH_3.CH.\begin{matrix} CONH_2 \\ \diagdown \\ \diagup \\ COOH \end{matrix}$$

The fourth observation shows that the second formula should be assigned to the compound, as dicarboxylic acids which contain the two carboxyl groups linked to the same carbon atom lose carbon dioxide on heating.

The examples which have been given to illustrate the methods employed to identify unknown substances, and to determine structure, have been selected on account of their simplicity and the readiness with which the observations recorded lead to definite conclusions. The steps involved in the study of many other compounds are equally obvious, but in the case of substances of more complicated structure the solution of the problem of their constitution is at times arrived at only after extended study. This is markedly true in the case of substances which do not contain the simple groups described up to this point. A number of important compounds which occur in nature contain their atoms linked in so-called rings and in other configurations. New principles must be developed before a conception of the structure of substances of this nature, such as uric acid, caffeine, etc., can be arrived at. A few examples will be given later.

When the structural formula of a compound has been deduced by the analytical method which has been illustrated, an attempt should be made to synthesize the compound. If the synthesis is carried out by reactions which can be followed step by step,

and leads finally to the original compound, the structural formula assigned to it may be considered to rest on a firm experimental basis.

Problems

1. Write out in the form of a table the behavior of unsaturated compounds, hydrocarbons, acids, alcohols, aldehydes, ketones, ethers, esters, anhydrides, amines, amides, and halogen compounds with the following reagents: water, cold solution of sodium hydroxide, hot solution of sodium hydroxide, dilute hydrochloric acid, cold concentrated sulphuric acid, acetyl chloride, sodium, bromine, solution of sodium carbonate, and phenylhydrazine.

2. The behavior of a number of organic compounds with the reagents listed in the question above was studied. The positive results as well as other tests suggested by these are given below. State to what class each compound belongs, and by reference to tables of the physical properties of organic compounds determine the particular compounds described:

a. The compound contains no elements other than C, H, and O. It boils at 142.5°. It is insoluble in water. When boiled with a solution of sodium hydroxide, an oil is formed which boils at 130.5°.

b. The compound contains no elements other than C, H, and O. It boils at 140.9°, dissolves without decomposition in cold concentrated sulphuric acid, is not affected by a hot solution of sodium hydroxide, and yields when heated with a strong solution of hydriodic acid a liquid which boils at 127°.

c. The compound contains no elements other than C, H, and O. It boils at 82.5°, reacts with sodium, and forms a compound when treated with acetyl chloride that boils at 89°.

d. The compound contains chlorine, boils at 78°, is lighter than water and does not react with it. It is converted by sodium into a hydrocarbon that boils at 126°.

e. The compound contains no elements other than C, H, and O. It melts at 135°, is soluble in water, liberates CO_2 from sodium carbonate. When heated above its melting point, CO_2 is given off and the liquid that condenses boils at 141°.

f. The compound contains nitrogen, melts at 132°, and is soluble in water. When it is boiled with a solution of sodium hydroxide, ammonia is liberated. When the resulting solution is acidified, CO_2 is evolved.

g. The compound contains nitrogen. It boils at 104°, reacts with acetyl chloride, and with hydrochloric acid. The solutions in acids yield, when treated with nitrous acid, nitrogen and an oil that boils at 137.9°.

3. Write the graphic formulas of the compounds which yielded the results given below:

a. The compound $C_6H_{14}O$ when boiled with a large excess of hydriodic acid gave the compounds C_2H_5I and C_4H_9I.

b. The compound C_2H_2BrClO was converted by cold water into the compound $C_2H_3BrO_2$.

c. The compound $C_2H_4O_3$ when treated with sodium hydroxide gave the compound $C_2H_3NaO_3$, and with PBr_3 gave the compound $C_2H_2Br_2O$.

d. The compound $C_5H_{14}NCl$ was converted into the compound $C_5H_{13}N$ when treated with a solution of sodium hydroxide, and into the compound $C_5H_{12}O$ when treated in solution with nitrous acid.

CHAPTER XVIII

AROMATIC HYDROCARBONS

432. When organic compounds were first carefully studied they were divided into two classes which were designated by the terms *aliphatic* and *aromatic*. To the first class belong the compounds which have been discussed up to this point. The term aliphatic is derived from the Greek word signifying "fat." Many of the acids which can be derived from the hydrocarbons of the methane series were first isolated from fats. The relation seemed an important one, and consequently the acids so derived and the compounds prepared from them were called aliphatic compounds. The term *aromatic* was applied to certain substances found in the vegetable kingdom which possess an agreeable odor, such as oil of bitter almonds, vanilla, and oil of wintergreen. This apparently arbitrary classification of organic substances has survived, as investigation has shown that the chemical properties of the two classes of compounds are markedly different. The possession of an odor is not characteristic, however, of the so-called "aromatic compounds." The study of the chemical composition of these compounds has shown that they are all derived from the hydrocarbon benzene, C_6H_6. The chemical properties which differentiate the aromatic compounds, more or less distinctly, from the aliphatic compounds, result from the fact that in many of its reactions with other substances benzene differs markedly from the aliphatic hydrocarbons.

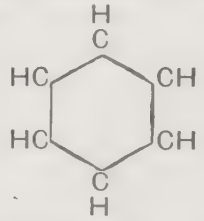
The radicals derived from the aromatic hydrocarbons are called *aryl radicals;* C_6H_5 is called phenyl, $CH_3C_6H_4$ is tolyl, $(CH_3)_2C_6H_3$ is xylyl, etc.

More than one-half of the organic compounds studied up to the present time belong to the aromatic series. Many of these are manufactured in large quantities and are used as drugs, dyes, flavoring extracts, food preservatives, etc.

433. Structure of Benzene.—It is necessary at the outset to form a conception of the structure of the benzene molecule.

Benzene contains but six hydrogen atoms in combination with six carbon atoms. This fact would lead to the view that the hydrocarbon is a highly unsaturated compound, as hexane, the paraffin which contains six carbon atoms, has the composition C_6H_{14}. In most of its reactions benzene acts like a saturated compound. Under certain conditions, however, it unites with bromine and forms the compound $C_6H_6Br_6$. If benzene were an unsaturated compound related to hexane, it should unite with eight atoms, as six carbon atoms joined as such atoms are joined in the aliphatic compounds, can hold in combination 14 univalent atoms. This fact shows clearly that we must look for an arrangement of atoms in benzene quite different from that found among the unsaturated compounds of the aliphatic series.

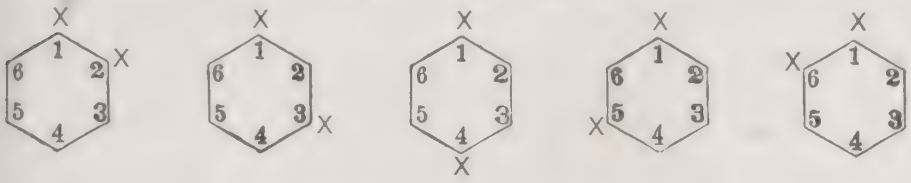
A definite view of the structure of benzene is arrived at from a consideration of two important facts. These are: first, benzene forms but one monosubstitution product with bromine or other atom or group; and, second, when two hydrogen atoms are replaced by two atoms or groups, but three isomeric disubstitution products can exist. The fact that but one bromobenzene, C_6H_5Br, exists, indicates that all six hydrogen atoms of benzene bear the same relation to the molecule. An elaborate series of experiments showed that all the hydrogen atoms are alike. One after another was replaced by the amino group, and the products obtained in all cases were identical. A number of structural formulas of benzene have been devised to fulfill the requirement of the equivalence of the six hydrogen atoms. Kekulé suggested that benzene consists of six CH groups joined in a ring:



Such a configuration is symmetrical, and is in accord with the fact that but one monosubstitution product of benzene is possible.

This view of the structure of benzene must now be tested in regard to the fact that three, and only three, disubstitution products exist. The formulas of the disubstitution products of a hydrocarbon of the structure indicated are given below. For

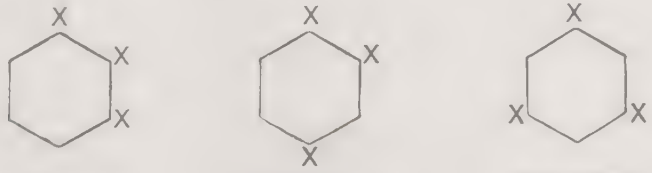
brevity it is usual to represent the structure of benzene by a hexagon, it being assumed that a CH group is situated at each angle. A symbol placed at an angle indicates that the hydrogen atom has in this place been replaced by the atom indicated by the symbol. The angles are frequently numbered for reference.



As the formula assigned to benzene is symmetrical, it is evident that the formulas in which the X's are in the positions 1, 2 and 1, 6 are identical. Those in which the substituents are in the positions 1, 3 and 1, 5 are likewise the same. It is thus seen that a hydrocarbon which consists of six CH groups arranged in a ring should yield three disubstitution products. This conclusion is further evidence of the correctness of the ring structure assigned to benzene.

In order to designate the structure of disubstitution products, names have been assigned to the isomers. Those in which the substituents are joined to adjacent carbon atoms (1, 2) are called *ortho* compounds, those in which the substituents are in the positions 1, 3 are called *meta* compounds, and those in the positions 1, 4 are *para* compounds. The abbreviations *o-*, *m-*, and *p-* are used in naming such substitution products.

The correctness of the formula for benzene can be tested further by considering the relation between the theory and the facts in the case of tri- and tetra-substitution products. The theory leads to the view that trisubstitution products which contain but one kind of substituent, should exist in three forms. Three, and only three, such isomers exist. The formulas and names of these are as follows:



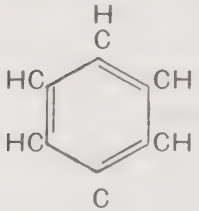
Adjacent or vicinal
1, 2, 3 or *v-*

Asymmetrical
1, 2, 4 or *as-*

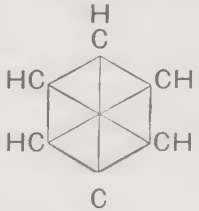
Symmetrical
1, 3, 5 or *s-*

If the substituents are dissimilar, a larger number of isomers is possible. The substitution products which contain four similar groups exist in three forms—the number which is in accord with the theory. On account of the ring structure assigned to benzene and its homologues, they are called *cyclic* compounds.

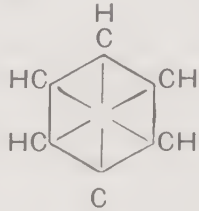
The formula of benzene which has been discussed does not take into account the fourth valence of the carbon atoms. Many suggestions have been put forward in regard to the position of this fourth bond. The formulas of Kekulé, Claus, Armstrong and Baeyer, and Thiele are as follows:



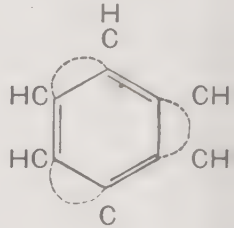
Kekulé



Claus



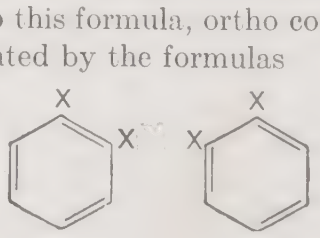
Armstrong and Baeyer



Thiele

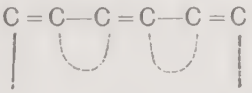
In the formula of Kekulé the carbon atoms are joined alternately by double bonds. According to Claus, each carbon atom is in combination with the carbon atom opposite to it in the molecule. The so-called centric formula of Armstrong and Baeyer is meant to indicate that the combining powers of the carbon atoms which are not utilized in the ring formation and in holding the hydrogen atoms, mutually neutralize one another, and no carbon atom is united directly to another carbon atom by the fourth bond. The formula of Thiele contains a system of conjugated double bonds (**51**).

There are objections which can be raised to all these formulas. While that of Kekulé accounts for the fact that benzene can unite with six bromine atoms, as it contains three double bonds, it is not in accord with the fact that but one orthodibromobenzene exists. According to this formula, ortho compounds should exist in the forms represented by the formulas



In the compound represented by the first formula the substituents are in combination with carbon atoms linked by a double bond, and in the second by a single bond. Kekulé overcame this objection by the assumption that the combination of the fourth bonds is dynamic, *i.e.*, that the double union shifts from between the carbon atoms numbered 1 and 2 to those numbered 1 and 6. A similar shifting takes place also with the other double bonds. Objections have been raised to the other formulas.

If a model of the benzene ring having the configuration represented by the formula of Armstrong and Baeyer is examined, it will be seen that it leads to the view that disubstitution products containing two dissimilar substituents joined to adjacent carbon atoms should exist in two stereoisomeric forms. No case of such isomerism has ever been observed. The formula of Thiele is, on the whole, the most satisfactory. It will be recalled (**51**) that when addition takes place to a conjugated system of double bonds, the atoms at the end of the chain show activity. In the case of the system represented by the following straight chain



addition would take place at the end carbon atoms since the unsaturation indicated by the other double bonds has become inactive as the result of the neutralization of the partial valences. If the end carbon atoms in the above chain are joined, the free partial valences in these atoms neutralize each other and the unsaturation of the molecule largely disappears. Such a configuration is indicated in the formula for benzene proposed by Thiele, which is given above.

In most of its reactions benzene acts like a saturated compound, and the fourth valence of the carbon atoms does not come into play. The hydrocarbon does not react with an aqueous solution of potassium permanganate, and does not show therefore the behavior which is characteristic of the unsaturated hydrocarbons of the aliphatic series.

434. Sources of Aromatic Compounds.—Many compounds which may be considered as derived from benzene, occur in the vegetable kingdom. Some of these will be described later.

The source which yields the large quantities of benzene and it homologues used in the manufacture of many substances of industrial importance, is coal tar.

435. *Coal tar* is formed in the manufacture of illuminating gas from bitu minous coal and is also obtained from by-product coke ovens. From th mixture the aromatic hydrocarbons are separated by distillation and b chemical means. Coal tar contains three classes of compounds: hydro carbons, which are not affected by acids or alkalies; phenols, which dissolv in alkalies; and basic substances, which dissolve in acids. The tar is firs distilled, and the distillate collected in fractions. The "light oil" is collecte between 105° and 210°; it contains benzene, toluene, xylenes, and sma quantities of thiophene, phenols, and pyridine bases. The next fractio called "carbolic oil," which is collected up to 240°, contains phenols an naphthalene. The "creosote oils," which are collected between 240° an 270°, contain naphthalene, cresols, naphthol, and other compounds. Th product obtained from this fraction after the removal of naphthalene, i used in preserving timber and railroad sleepers, and in destroying vermi If the distillation is stopped at 270° the residue left in the still is calle soft pitch. If anthracene is to be obtained the distillation is continued The "anthracene oil," which distills above 270°, contains about 10 per cen of anthracene together with carbazol, liquid oils, and solid hydrocarbons such as phenanthrene and chrysene. The hard pitch left in the still is use as a black varnish for painting metal work and for making tarred pape It is mixed with asphalt for making pavements.

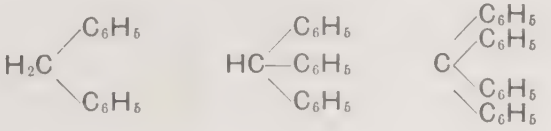
The products obtained by the first distillation are redistilled and separate into fractions, which are treated with acids to remove basic substances an with bases to remove phenols. Final fractionations yield the commercia product used in chemical industry. Phenol, or carbolic acid, is separate from the "carbolic oil" by treatment with sodium hydroxide, in which th phenol is soluble. The alkaline solution, after separation from insolubl oils, is acidified, when the phenol separates as an oil. From the higher boiling distillates naphthalene and anthracene crystallize out on cooling These hydrocarbons are separated by filtration and pressure, and ar purified by distillation or sublimation.

The approximate percentages of the purified products obtained from coa tar are as follows: benzene and toluene, 0.22; xylene and solvent naphtha 0.62; phenol, 0.4; cresols, 1.13; naphthalene, 6.4; anthracene 0.44.

436. Classes of Aromatic Hydrocarbons.—A large numbe of hydrocarbons may be considered as derivatives of benzen formed by the replacement of one or more hydrogen atoms by radicals. Benzene bears the same relation to the aromatic hydrocarbons that methane bears to the paraffins. Toluene, which has the formula $C_6H_5.CH_3$, is methyl-benzene; the three

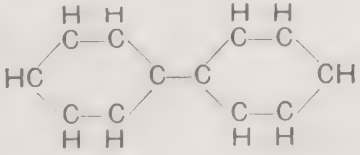
xylenes are dimethyl-benzenes, $C_6H_4.(CH_3)_2$; cymene is para-methyl-isopropyl-benzene, $C_6H_4.(CH_3)(C_3H_7)$, etc. The radicals which are joined to the benzene ring are called "side chains." The side chain may be a radical derived from an unsaturated hydrocarbon. Among the hydrocarbons of this class are styrene, $C_6H_5.CH=CH_2$, which is a phenyl derivative of ethylene, and phenyl-acetylene, $C_6H_5.C\equiv CH$.

An important class of hydrocarbons includes substances which contain two or more benzene rings. Such hydrocarbons may be considered as derived from methane and its homologues by replacing hydrogen atoms by phenyl radicals. Diphenylmethane, triphenylmethane, and tetraphenylmethane, the formulas of which are given below, belong to this class:

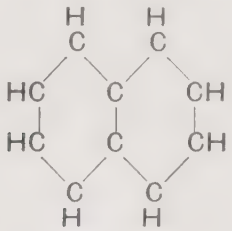


Analogous derivatives of ethane and other hydrocarbons are known. Diphenylethane, $C_6H_5CH_2.CH_2C_6H_5$, and tetraphenylethane, $(C_6H_5)_2CH.CH(C_6H_5)_2$, are examples. Similar substitution products of unsaturated hydrocarbons are of interest. Tetraphenylethylene, $(C_6H_5)_2C=C(C_6H_5)_2$, will be described later.

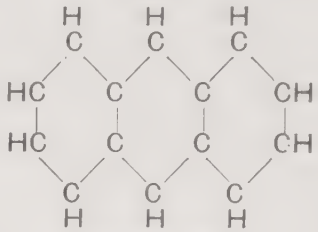
Important hydrocarbons are known in which two or more benzene rings are more directly united than in the cases just mentioned. Biphenyl, $C_6H_5.C_6H_5$, consists of two rings in direct combination. Derivatives of this hydrocarbon exist in which one or more hydrogen atoms are replaced by alkyl radicals. In these compounds the two benzene rings are joined by a single bond. The arrangement of the carbon atoms in biphenyl is represented by the following formula:



Naphthalene and anthracene, which contain benzene rings are built up in a different way:



Naphthalene



Anthracene

The hydrocarbons of this class resemble closely the simple benzene derivatives (see Sec. **459** and **463**).

437. Preparation of Aromatic Hydrocarbons.—A number of methods of preparing the hydrocarbons of this class are general in their application. The more important will be mentioned here. Certain special methods will be described under the compounds to which they may be applied with advantage.

The *Fittig synthesis* is an application of the Wurtz synthesis (**25**) to the preparation of aromatic compounds. It is carried out by treating an ethereal solution of a halogen derivative of an aromatic hydrocarbon and an alkyl halide with sodium. Toluene may be prepared in this way from bromobenzene and methyl iodide:

$$C_6H_5Br + CH_3I + 2Na = C_6H_5.CH_3 + NaI + NaBr$$

When dibromobenzene is used, the halogen atoms are replaced by two alkyl groups. The method is of particular value, as by means of it compounds of definite structure may be prepared. Meta-dibromobenzene is converted, for example, into meta-xylene when treated with methyl iodide and sodium.

Two or more benzene rings can be united by the application of the Fittig synthesis. Bromobenzene and sodium yield biphenyl:

$$2C_6H_5Br + 2Na = C_6H_5.C_6H_5 + 2NaBr$$

Other methods of preparation analogous to the Fittig synthesis are frequently used. In the case of certain compounds the halogen atoms are more readily removed by zinc or silver. Tetraphenylethane is conveniently prepared by treating a solution of diphenylbromomethane with zinc:

$$2(C_6H_5)_2CHBr + Zn = (C_6H_5)_2CH.CH(C_6H_5)_2 + ZnBr_2$$

When diphenyldichloromethane is treated with zinc a derivative of ethylene is formed:

$$2(C_6H_5)_2CCl_2 + 2Zn = (C_6H_5)_2C:C(C_6H_5)_2 + 2ZnCl_2$$

Friedel and Crafts Synthesis.—In the presence of anhydrous aluminium chloride, aliphatic halogen compounds react with aromatic hydrocarbons and form condensation products as the result of the elimination of hydrogen halide. Thus, when a mixture of benzene and aluminium chloride is treated with methyl chloride, toluene is formed:

$$C_6H_6 + CH_3Cl \overset{AlCl_3}{=} C_6H_5.CH_3 + HCl$$

As toluene reacts under the same conditions with methyl chloride and forms xylene (dimethylbenzene), and the latter forms trimethylbenzene, etc., it is evident that a pure compound cannot be obtained readily by this reaction. The hydrocarbons formed may be separated by fractional distillation.

The Friedel and Crafts synthesis is of particular value in the preparation of certain classes of hydrocarbons. Diphenylmethane is best prepared in this way from benzyl chloride, $C_6H_5CH_2Cl$:

$$C_6H_5CH_2Cl + C_6H_6 \overset{AlCl_3}{=} C_6H_5CH_2C_6H_5 + HCl$$

Chloroform and benzene furnish a good yield of triphenylmethane:

$$CHCl_3 + 3C_6H_6 \overset{AlCl_3}{=} CH(C_6H_5)_3 + 3HCl$$

It is important to note that halogen compounds in which the halogen atom is joined to a carbon atom in the benzene ring cannot be used instead of the halogen derivatives of the paraffin hydrocarbons. Chlorobenzene and benzene do not interact under the influence of aluminium chloride. The presence of the halogen atom in the benzene ring does not interfere, however, with the condensation. Chloroform and chlorobenzene yield tri[*p*-chlorophenyl] methane. In brief, the halogen atom which is eliminated as hydrogen halide must be one which is not linked to a carbon atom in a ring; in nearly all cases the hydrogen atom so eliminated is one which is linked to such a carbon atom.

The action of aluminum chloride in effecting the condensation of halogen compounds with aromatic hydrocarbons results, in all

probability, from the fact that these hydrocarbons form wit anhydrous aluminium chloride, addition products that are muc more reactive than the hydrocarbons themselves.

438. Acyl chlorides react with aromatic hydrocarbons in the presence o aluminium chloride. The reaction furnishes a convenient method of prepar ing ketones. The preparation of methyl phenyl ketone is an example

$$CH_3COCl + C_6H_6 \xrightarrow{AlCl_3} CH_3COC_6H_5 + HCl$$

The manner in which aluminium chloride effects the condensation of halide and a hydrocarbon has been carefully studied. It has been found tha in certain cases the aluminium chloride forms an addition product with th hydrocarbon, which enters into reaction with the alkyl or other halide. I other cases, the inorganic halide forms a compound with the organic halide which, in turn, reacts with the hydrocarbon. Intermediate products hav been isolated in a number of cases. The one formed from aluminium chlo ride and the chloride of benzoic acid, C_6H_5COOH, can be obtained in well formed crystals; it has the composition $C_6H_5COCl.AlCl_3$. When thi compound is treated with benzene, reaction takes place and a halogen aton is replaced by the phenyl radical:

$$C_6H_5COCl.AlCl_3 + C_6H_6 = C_6H_5COC_6H_5.AlCl_3 + HCl$$

The compound of aluminium chloride and the resulting ketone, in this case diphenyl ketone, can be obtained in crystalline condition. When treated with water it is decomposed and the ketone and aluminium chloride are formed.

The results obtained in the study of the mechanism of these reactions are of the greatest importance, as they throw light on the nature of so-called cat alytic reactions. For a long time the part played by aluminium chloride in effecting condensations was unknown. The substance was said to be a cat alytic agent. The results just outlined show that, in this case at least, the reaction is brought about as the result of the formation of an addition product of one of the reacting substances and the catalytic agent, and that the product so formed possesses properties unlike those of the compounds from which it is formed. It is reasonable that the addition of aluminium chloride to a compound should materially alter the reactivity of the elements which the compound contains. Recent work in other directions in the study of catalytic action indicates strongly that in many cases the effect of the catalytic agent is brought about as the result of its union with one of the reacting substances.

439. *Grignard Synthesis.*—Magnesium reacts with halogen derivatives of the aromatic hydrocarbons as well as with those derived from the paraffins. The compounds so formed are decomposed by water, and hydrocarbons are formed. By the

application of this method a halogen compound can be converted into the corresponding hydrocarbon:

$$C_6H_5MgBr + H_2O = C_6H_6 + Mg.OH.Br$$

The magnesium compounds react also with halides:

$$C_6H_5CH_2Cl + CH_3MgI = C_6H_5CH_2CH_3 + MgI.Cl$$

Tetraphenylmethane may be prepared by the reaction expressed by the following equation:

$$(C_6H_5)_3C.Cl + C_6H_5MgBr = (C_6H_5)_4C + MgBrCl$$

Unsaturated hydrocarbons are readily prepared from ketones and alkyl chlorides by Grignard's synthesis. The reaction first yields a tertiary alcohol, which at a higher temperature loses water and passes into a hydrocarbon. Diphenyl ketone, for example, gives, with methylmagnesium diphenylethylene:

$$(C_6H_5)_2CO \longrightarrow (C_6H_5)_2C\begin{matrix}\diagup OMgI \\ \\ \diagdown CH_3\end{matrix} \longrightarrow (C_6H_5)_2C\begin{matrix}\diagup OH \\ \\ \diagdown CH_3\end{matrix} \longrightarrow$$

$$(C_6H_5)_2C{=}CH_2$$

440. *Other Syntheses.*—As in the case of the aliphatic compounds, aromatic hydrocarbons are formed when salts of acids are distilled with sodium hydroxide or soda lime. Benzene can be prepared from benzoic acid in this way:

$$C_6H_5.COONa + NaOH = C_6H_6 + Na_2CO_3$$

The sulphonic acids derived from the aromatic hydrocarbons are decomposed when heated with water under pressure. Hydrochloric acid facilitates the reaction. Toluene-sulphonic acid yields toluene:

$$CH_3.C_6H_4.SO_3H + HOH = CH_3.C_6H_5 + H_2SO_4$$

The hydroxyl derivatives of the aromatic hydrocarbons are reduced when heated with zinc dust:

$$C_6H_5OH + Zn = C_6H_6 + ZnO$$

441. Characteristic Reactions of the Aromatic Compounds. *Nitration.*—It has been stated that the aromatic compounds differ markedly from the paraffins and the unsaturated hydrocarbons related to ethylene and acetylene. The reactions which take place when benzene and its derivatives are treated with

nitric acid, sulphuric acid, or oxidizing agents are characteristic of this group of compounds. Only the higher paraffins react with nitric acid, and in the case of these compounds reaction results to but a slight degree and only after heating for many hours (**31**). The aromatic hydrocarbons and their substitution products form well-characterized compounds when treated with nitric acid. When benzene is warmed with concentrated nitric acid nitrobenzene is formed:

$$C_6H_6 + HO.NO_2 = C_6H_5.NO_2 + H_2O$$

The nitro compounds are of the greatest importance and will be fully discussed later.

Sulphonation.—Benzene is converted into benzene-sulphonic acid when heated with concentrated sulphuric acid:

$$C_6H_6 + HO.SO_2.OH = C_6H_5.SO_2.OH + H_2O$$

The sulphonic acid may be considered as derived from sulphuric acid by the replacement of a hydroxyl group by a radical.

Oxidation.—The paraffins resist to a marked degree the action of oxidizing agents. The aromatic compounds which contain side chains are oxidized when treated with dilute nitric acid, potassium chromate, potassium permanganate, or other active oxidizing agents. Toluene and ethylbenzene are converted by oxidizing agents into benzoic acid:

$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$

$$C_6H_5.CH_2CH_3 + 6O = C_6H_5.COOH + CO_2 + 2H_2O$$

In general, a side chain, whatever its length or configuration, is converted by active oxidizing agents into a single carboxyl group. A xylene, which contains two methyl groups joined to different carbon atoms, yields a dibasic acid on oxidation:

$$C_6H_4(CH_3)_2 + 6O = C_6H_4(COOH)_2 + 2H_2O$$

442. Benzene, C_6H_6, was discovered in 1825 by Faraday in the liquid obtained from compressed oil gas. It was first isolated from coal tar in 1845 by A. W. Hofmann. The hydrocarbon is of the greatest importance on account of the fact that it is the substance from which the aromatic compounds are derived. It is obtained in large quantities from coal tar, and is used in the manufacture of many compounds which find extensive use. Benzene has been isolated from California petroleum. Benzene

melts at 5.5° and boils at 79.6°; its specific gravity is $0.878^{\frac{20°}{4°}}$. That obtained from coal tar contains thiophene, C_4H_4S, from which it cannot be separated by distillation. The sulphur compound is extracted from benzene by shaking the latter with concentrated sulphuric acid. The pure hydrocarbon is obtained by the process of alternate freezing and melting, which has been described (9).

Benzene is formed when acetylene is passed through a hot tube, $3C_2H_2 = C_6H_6$, and when kerosene is heated under pressure. It is also obtained when sodium benzoate is heated with sodium hydroxide. Pure benzene, free from thiophene, was first obtained in this way. Some of the earlier investigations of benzene were carried out with the hydrocarbon prepared from benzoic acid. The reaction is analogous to that by which methane may be prepared from acetic acid:

$$C_6H_5COONa + NaOH = C_6H_6 + Na_2CO_3$$

Benzene reacts with chlorine in the sunlight and forms an addition product called benzene hexachloride, $C_6H_6Cl_6$. The effect of a carrier[1] on the reaction between a halogen and a hydrocarbon can be readily shown when benzene is treated with bromine. When bromine is added to benzene, no reaction appears to take place at first. If a little powdered iron or aluminium is added, reaction soon begins and hydrogen bromide is rapidly evolved. If equal molecular quantities of the hydrocarbon and halogen are used, and the mixture is kept cold, the chief product of the reaction is bromobenzene. If more bromine is used and the mixture is allowed to grow warm, para-dibromobenzene is formed.

When benzene is warmed and shaken with concentrated sulphuric acid, it dissolves slowly and is converted into benzenesulphonic acid, which is soluble in water, and resembles sulphuric acid somewhat in physical properties. In order to increase the yield of sulphonic acid a mixture of sulphuric acid and sulphur trioxide is often used. The reaction takes place according to the following equation:

$$C_6H_6 + HO.SO_2OH = C_6H_5.SO_2OH + H_2O$$

[1] The so-called halogen carriers, such as iron, iodine, and aluminium chloride, are catalytic agents, which increase the rate of reaction between the halogens and organic compounds.

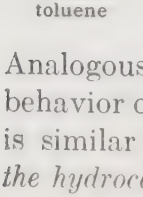
Hot concentrated nitric acid converts benzene into nitrobenzene, which is a heavy oil, insoluble in water:

$$C_6H_6 + HO.NO_2 = C_6H_5.NO_2 + H_2O$$

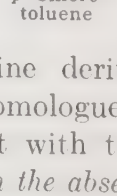
When a large excess of nitric acid is used meta-dinitrobenzene is formed. In the introduction of nitro groups into hydrocarbons a mixture of nitric acid and sulphuric acid is generally used.

443. Toluene, $C_6H_5.CH_3$, is obtained from coal tar. It is formed in appreciable quantities when kerosene is heated under pressure, and when the higher homologues of benzene, such as the xylenes, cumenes, etc., are boiled with anhydrous aluminium chloride. Toluene melts at $-95.1°$ and boils at 110.5°, and has the specific gravity $0.866^{20°}_{4°}$. It may be prepared by the use of the general methods which have been described.

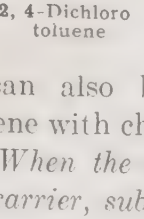
The reaction of toluene with chlorine and bromine presents some points of interest. When the hydrocarbon is treated with chlorine in the sunlight, or the halogen is passed into the boiling hydrocarbon, substitution in the side chain takes place. In this way compounds of the formulas $C_6H_5.CH_2Cl$, $C_6H_5.CHCl_2$ and $C_6H_5.CCl_3$ are formed. The compounds are called, respectively, benzyl chloride, benzal chloride, and benzotrichloride. When the halogen reacts with toluene in the presence of a carrier, the substituent enters the ring, and chlorotoluenes are formed. The number of chlorine atoms which enter is determined by the amount of halogen used and the temperature. A mixture of the ortho and para compounds is first obtained; a dichlorotoluene and a trichlorotoluene can also be formed. The structure of these compounds is represented by the formulas:



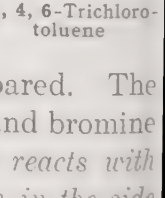
o-Chloro-toluene



p-Chloro-toluene



2, 4-Dichloro toluene



2, 4, 6-Trichloro-toluene

Analogous bromine derivatives can also be prepared. The behavior of the homologues of benzene with chlorine and bromine is similar to that with toluene. *When the halogen reacts with the hydrocarbon in the absence of a carrier, substitution in the side*

chain takes place. In the presence of a carrier the substituent enters the ring. It will be recalled that the paraffins react with chlorine in the sunlight, and substitution products are formed. When toluene is treated with the halogen under the same conditions it acts as a derivative of methane, phenylmethane, $CH_3.C_6H_5$, and the hydrogen atoms joined to the methane carbon atom are replaced.

Nitric acid and sulphuric acid react with toluene, and nitro compounds and sulphonic acids are formed as the result of the replacement of hydrogen atoms in the ring. The positions in the molecule taken by the entering group are the same as those taken by the halogens.

When toluene is boiled with dilute nitric acid or a solution of potassium dichromate and sulphuric acid, the side chain is oxidized to a carboxyl group, and benzoic acid is formed:

$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$

The reaction takes place slowly on account of the insolubility of the hydrocarbon in water. The oxidation of the side chains in compounds which are soluble in water takes place, in general, with ease. For example, toluic acid is readily oxidized to phthalic acid when warmed with a solution of potassium permanganate:

$$CH_3.C_6H_4.COOH + 3O = C_6H_4(COOH)_2 + H_2O$$

444. Xylenes, $C_6H_4(CH_3)_2$.—The three xylenes occur in coal tar. On account of the fact that their boiling points are so nearly alike, they cannot be separated by distillation. Orthoxylene boils at 144°, metaxylene at 139°, and paraxylene at 137.7°. They melt respectively, at −27.1°, −53.6°, and 13.2°. They can be prepared in the pure condition by Fittig's synthesis. They can be obtained, nearly pure, from coal tar by chemical means, the separation being effected by a method which is based on the difference in reactivity of the isomers with sulphuric acid and with oxidizing agents.

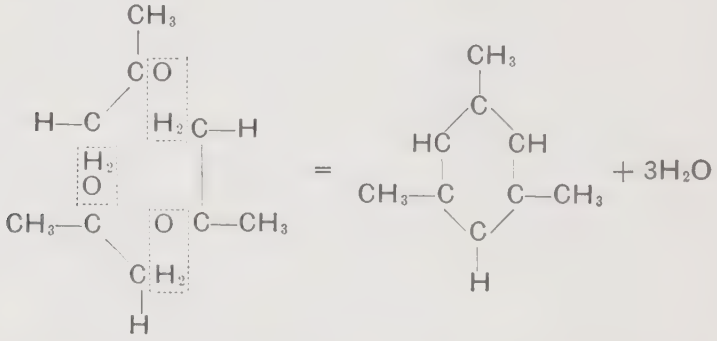
445. Cymene, $C_6H_4(CH_3)(iso\text{-}C_3H_7)(1, 4)$, is para-methylisopropylbenzene. It is a constituent of a number of essential oils, such as oil of caraway, oil of lemon, oil of thyme, and oil of eucalyptus. It can be prepared by Fittig's synthesis from

p-bromoisopropylbenzene. It is most readily prepared by warming camphor with phosphorus pentoxide:

$$C_{10}H_{16}O \xrightarrow{P_2O_5} C_{10}H_{14} + H_2O$$

Cymene boils at 176° and has the specific gravity 0.857 $\frac{20°}{4°}$.

446. Mesitylene, $C_6H_3(CH_3)_3(1, 3, 5)$, symmetrical trimethylbenzene, is found in coal tar. It boils at 164.6° and has the specific gravity $0.863^{\frac{20°}{4°}}$. The hydrocarbon is most readily obtained by the action of concentrated sulphuric acid on acetone. If the two substances are mixed and distilled after standing some time, mesitylene is obtained. The yield is small, being from 10 to 20 per cent of that calculated from the weight of acetone used. The reaction consists in the removal of water from acetone:



The condensation leads to the view that mesitylene has the symmetrical structure—a fact which has been established by evidence independent of this synthesis.

447. Diphenylmethane, $(C_6H_5)_2CH_2$, is best prepared from benzyl chloride, $C_6H_5CH_2Cl$, and benzene by the Friedel and Crafts synthesis. It melts at 27° and boils at 262°. Homologues of this compound can be prepared from aldehydes and aromatic hydrocarbons by the action of sulphuric acid. Thus, aldehyde or acetal and benzene when shaken with sulphuric acid give diphenyl-methyl-methane (unsymmetrical diphenylethane):

$$CH_3CHO + 2C_6H_6 = CH_3CH(C_6H_5)_2 + H_2O$$

Ditolylmethane may be prepared from methylene chloride and toluene in the presence of aluminium chloride:

$$CH_2Cl_2 + 2C_6H_5.CH_3 = CH_2(C_6H_4.CH_3)_2 + 2HCl$$

Diphenylmethane and similar compounds are converted into nitro derivatives when heated with nitric acid, and into sulphonic acids by sulphuric acid. When oxidized with chromic acid, diphenylmethane gives diphenylketone (benzophenone):

$$(C_6H_5)_2CH_2 + O_2 = (C_6H_5)_2CO + H_2O$$

448. Triphenylmethane, $(C_6H_5)_3CH$, is an important hydrocarbon on account of its relation to the triphenylmethane dyes. It is prepared from chloroform and benzene by the Friedel and Crafts synthesis:

$$CHCl_3 + 3C_6H_6 = CH(C_6H_5)_3 + 3HCl$$

The reaction is not as simple a one as indicated by this equation. A number of products are formed from which it is necessary to separate triphenylmethane by distillation and crystallization. The hydrocarbon melts at 92.5° and boils at 359.2°. It forms a well-characterized addition product with benzene of the formula $(C_6H_5)_3CH.C_6H_6$, which crystallizes in rhombohedra, melts at 76°, and effloresces in the air. When dissolved in cold fuming nitric acid, triphenylmethane is converted into a trinitro derivative, in which the nitro groups are in the para position to the methane carbon atom. With chlorine, triphenylchloromethane, $(C_6H_5)_3CCl$, and with oxidizing agents, triphenylcarbinol, $(C_6H_5)_3C.OH$, are formed.

449. Diphenylethane.—The symmetrical compound, C_6H_5-$CH_2.CH_2C_6H_5$, is also called bibenzyl. It is formed from benzyl chloride by the Wurtz synthesis:

$$2C_6H_5CH_2Cl + 2Na = C_6H_5CH_2.CH_2C_6H_5 + 2NaCl$$

The method of preparing unsymmetrical diphenylethane, $(C_6$-$H_5)_2CH.CH_3$, was mentioned under diphenylmethane. The symmetrical compound melts at 52.5° and boils at 284°; unsymmetrical diphenylethane is a liquid which boils at 272°. Oxidizing agents convert the former into benzoic acid, and the latter into benzophenone.

450. Tetraphenylethane, $(C_6H_5)_2CH.CH(C_6H_5)_2$, is readily prepared by the action of zinc on a solution of diphenylbromomethane in ether or ethyl acetate:

$$2(C_6H_5)_2CHBr + Zn = (C_6H_5)_2CH.CH(C_6H_5)_2 + ZnBr_2$$

The hydrocarbon is a stable compound which melts at 209°. It is oxidized by chromic acid to benzophenone, $(C_6H_5)_2CO$. When passed through a red-hot tube the hydrocarbon loses hydrogen, and an unsaturated compound, tetraphenylethylene, $(C_6H_5)_2\ C{=}C(C_6H_5)_2$, is formed. Other hydrocarbons undergo a similar decomposition.

451. Hexaphenylethane, $(C_6H_5)_3C.C(C_6H_5)_3$.—A hydrocarbon (m.p. 147°) to which this structure has been assigned is of great interest on account of its remarkable properties. When a solution of triphenylchloromethane in benzene or other solvent is treated with zinc, reaction takes place at room temperature, and a hydrocarbon is obtained, which is characterized by its great activity. The reaction appears to be similar to that by which tetraphenylethane is formed from diphenylbromomethane, but the compound differs markedly in properties from the tetra-substitution product. It unites directly with oxygen of the air, and is converted into a peroxide of the structure $(C_6H_5)_3C{-}O{-}O{-}C(C_6H_5)_3$; with iodine, triphenyliodomethane, $(C_6H_5)_3CI$, is formed. The hydrocarbon forms more or less stable addition products with many compounds, such as ketones, paraffin hydrocarbons, ethers, etc. On account of its unusual behavior the hydrocarbon has been the subject of much investigation. Hexaphenylethane, or *triphenylmethyl* as it is usually called, exists in two forms; one is colorless and the other is yellow. When dissolved, the colorless form passes, in part, into the colored variety. A number of suggestions have been put forward to explain the relation between these two forms and the activity of the hydrocarbon. According to one of these, the colorless compound is hexaphenylethane and the form that is colored is triphenylmethyl, $(C_6H_5)_3C$. It is the latter form, in which a trivalent carbon atom is present, that exhibits the great chemical activity noted above. When hexaphenylethane is dissolved, it changes to some extent into triphenylmethyl, and an equilibrium between the two forms is established according to the following equation:

$$(C_6H_5)_3C.C(C_6H_5)_3 \rightleftharpoons 2(C_6H_5)_3C$$

When such a solution is brought into contact with oxygen, iodine, or certain other substances, the triphenylmethyl present reacts;

as a consequence the equilibrium is disturbed, more hexaphenylethane changes into triphenylmethyl, and finally all the hexaphenylethane enters into reaction. Measurements indicate that in a solution of the hydrocarbon there is present about 10 per cent of triphenylmethyl.

A study of compounds similar to hexaphenylethane has brought out the interesting fact that by replacing phenyl by other radicals, hydrocarbons are obtained that form solutions in which the proportion of the compound containing a trivalent carbon atom is greater than is the case with hexaphenylethane. When triphenyltriphenylmethyl chloride, $(C_6H_5.C_6H_4)_3CCl$, is treated with metals, the halogen atom is removed and a very active hydrocarbon, which has a violet color, is obtained; its molecular weight corresponds to the formula $(C_6H_5.C_6H_4)_3C$.

Recent experiments by Paneth indicate that the radical methyl, CH_3, which contains a trivalent carbon atom, can have a transitory existence. When tetramethyllead is heated, it dissociates into lead and a substance which reacts in the cold with lead and with antimony and forms the corresponding organometallic compounds containing methyl. The ability of the substance to form these compounds disappears in a small fraction of a second.

452. Styrene, $C_6H_5.CH=CH_2$, phenylethylene, or styrole, derives its name from its occurrence in storax. It can be prepared by methods which are indicated by its structure. The hydrocarbon bears the same relation to cinnamic acid, $C_6H_5CH=CHCOOH$, that benzene bears to benzoic acid. It can be prepared by heating sodium cinnamate with sodium hydroxide, or by simply distilling the free acid:

$$C_6H_5.CH:CH.COOH = C_6H_5.CH:CH_2 + CO_2$$

The preparation of styrene from a saturated compound is analogous to that of ethylene and its derivatives. When ethylbenzene is treated with bromine, the first product of the reaction has the structure $C_6H_5.CHBr.CH_3$. This substance loses hydrogen bromide when warmed with alcoholic potash:

$$C_6H_5.CHBr.CH_3 + KOH = C_6H_5.CH:CH_2 + KBr + H_2O$$

Another method of preparation is similar to one used to prepare derivatives of ethylene. When phenyl-methyl-carbinol, which

can be prepared by the Grignard synthesis, is heated with zinc chloride, styrene is formed:

$$C_6H_5.CHOH.CH_3 = C_6H_5.CH:CH_2 + H_2O$$

Styrene is an oil, with an aromatic odor, which boils at 146°. It unites with the halogens and hydrogen halides, and polymerizes to metastyrene, $(C_8H_8)_x$, on heating. With nitric acid its behavior is unusual; the nitro compound formed contains the nitro group in the side chain, $C_6H_5CH=CHNO_2$.

453. Stilbene, $C_6H_5CH=CHC_6H_5$ (m.p. 124°), can be prepared in a number of ways, two of which are represented by the following equations:

$$2C_6H_5CHCl_2 + 2Zn = C_6H_5CH:CHC_6H_5 + 2ZnCl_2$$
$$2C_6H_5CH_3 + 2PbO = C_6H_5CH:CHC_6H_5 + 2Pb + 2H_2O$$

Zinc and benzal chloride react at ordinary temperatures. The preparation from toluene is effected by passing the vapor of the hydrocarbon over heated lead oxide. Stilbene reacts with the halogens and halogen acids and forms a crystalline compound with nitrogen tetroxide, $(C_6H_5)_2C_2H_2.N_2O_4$.

454. Tetraphenylethylene, $(C_6H_5)_2C=C(C_6H_5)_2$ (m.p. 221°), is formed when a solution of diphenyl-dichloro-methane is treated with zinc:

$$2(C_6H_5)_2CCl_2 + 2Zn = (C_6H_5)_2C:C(C_6H_5)_2 + 2ZnCl_2$$

It is most conveniently prepared by boiling a mixture of benzophenone chloride and diphenylmethane:

$$(C_6H_5)_2CCl_2 + (C_6H_5)_2CH_2 = (C_6H_5)_2C:C(C_6H_5)_2 + 2HCl$$

The hydrocarbon does not show most of the properties characteristic of unsaturated compounds. It forms no addition product with bromine or the halogen hydrides. When treated with bromine, substitution products are obtained. It reacts with chlorine, however, and forms the compound $(C_6H_5)_2CCl$-$ClC(C_6H_5)_2$. The activity of compounds which contain a double bond is affected by the nature of the radicals in combination with the carbon atoms linked by this bond. In general, an increase in the number of radicals linked to the unsaturated

carbon atoms is associated with a decrease in the activity of the double bond toward the halogens.

455. Phenylacetylene, $C_6H_5C{\equiv}CH$, can be prepared by the application of the methods used to prepare derivatives of acetylene. Acetophenone, $C_6H_5.CO.CH_3$, like other ketones, is converted into a chloride, $C_6H_5.CCl_2CH_3$, by phosphorus pentachloride. When heated with alcoholic potash the chloro derivative is converted into phenylacetylene:

$$C_6H_5.CCl_2.CH_3 + 2KOH = C_6H_5C \quad CH + 2KCl + 2H_2O$$

Phenylacetylene boils at 143°, and shows the properties characteristic of derivatives of acetylene; it unites with four atoms of bromine and forms metallic derivatives.

456. Diphenylacetylene, $C_6H_5C{\equiv}CC_6H_5$ (m.p. 60°), is formed by boiling stilbene dibromide with alcoholic potash:

$$C_6H_5CHBr.CHBrC_6H_5 + 2KOH = C_6H_5C{\equiv}CC_6H_5 + 2KBr + 2H_2O$$

The hydrocarbon unites with halogens but does not form metallic derivatives. When heated with hydriodic acid and phosphorus it is reduced to stilbene.

457. Biphenyl, $C_6H_5.C_6H_5$, is formed, along with other hydrocarbons, when benzene is passed through a tube heated to redness, and by the action of sodium on an ethereal solution of bromobenzene:

$$2C_6H_5Br + 2Na = C_6H_5.C_6H_5 + 2NaBr$$

Biphenyl crystallizes from alcohol in large lustrous plates; it melts at 69° and boils at 254.9°. When treated with chlorine, bromine, nitric acid, or sulphuric acid, substitution products are formed. The possibility for isomerism among the derivatives of biphenyl is greater than in the case of the homologues of benzene. In order to indicate the position of substituents the carbon atoms in biphenyl are numbered according to the following scheme:

When biphenyl is brominated, compounds of the following structures are formed, 4-bromobiphenyl, 4,4′-dibromobiphenyl; and

when nitrated, 2-nitrobiphenyl, 4-nitrobiphenyl, 2,4′-dinitrobiphenyl, and 4,4′-dinitrobiphenyl. Higher substitution products are also obtained. It is seen that the ortho and para positions are the ones taken by the entering group. In this respect the hydrocarbon resembles toluene.

Biphenyl is converted by active oxidizing agents into benzoic acid, $C_6H_5.COOH$. The structure of the substitution products of the hydrocarbon is established by oxidation. The nitrobiphenyl which is converted into *p*-nitrobenzoic acid evidently has the nitro group in position 4. Substitution products of biphenyl which contain the amino group are used in the manufacture of important dyes.

The hydrocarbon is prepared from benzene on an industrial scale; it is largely used as a heat-transfer agent and in the preparation of polychloro derivatives that are finding a number of applications on account of their high boiling points, low inflammability, and other properties.

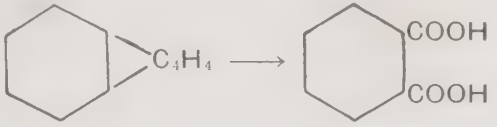
458. Naphthalene, $C_{10}H_8$, is present to the extent of about 6 per cent in coal tar, from which it is obtained in large quantities. Naphthalene melts at 80.1° and boils at 217.9°. It forms a molecular compound with picric acid (**605**), which is useful in its identification; it has the formula $C_{10}H_8.C_6H_2(NO_2)_3OH$ and melts at 149°.

Naphthalene is soluble in hot alcohol and in ether. It is very volatile, has a characteristic penetrating odor, and is used extensively instead of camphor to protect woolen goods and furs from moths. The luminosity of coal gas is largely dependent on the naphthalene which it contains. The hydrocarbon is used to prepare compounds from which important dyes are manufactured.

Naphthalene is formed when the vapors of many compounds are passed through a red-hot tube. It can be synthesized by methods which lead to a definite view of its structure.

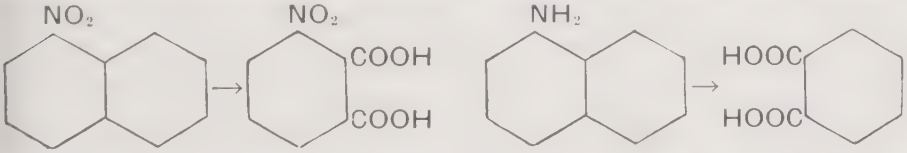
459. The *structure of naphthalene* has been determined by a study of the compounds formed as the result of the oxidation of the hydrocarbon and certain of its derivatives. When naphthalene is treated with active oxidizing agents it is converted into phthalic acid, a dicarboxylic acid derived from benzene, in which the carboxyl groups have been shown to be in the ortho position.

This fact indicates that naphthalene contains a benzene ring to which side chains are united in the ortho position:

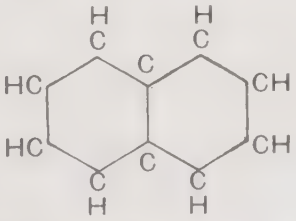


Phthalic acid

The configuration of the side chain is determined in the following way: Nitronaphthalene is converted into nitrophthalic acid by oxidation. If the nitro group is reduced to the amino group, and the resulting aminonaphthalene is oxidized, phthalic acid is obtained. It is evident that, in the latter case, the oxidation destroys the ring to which the amino group is attached, and as phthalic acid is formed, it follows that the side chain consists of a second benzene ring. The oxidation of the nitro and amino derivatives of naphthalene is expressed by the following formulas:



The difference between the action of oxidizing agents on the nitro derivative and the amino derivative is observed in the case of other compounds. Benzene derivatives which contain an amino group are readily decomposed by oxidizing agents, whereas rings which contain nitro groups are stable. The structure of naphthalene is expressed by the formula

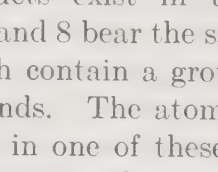


No entirely satisfactory formula for the hydrocarbon which takes into account the fourth bonds of the carbon atoms has been proposed.

460. *Chemical Properties.*—Naphthalene resembles benzene closely in its behavior with reagents. When it is treated with a

mixture of potassium chlorate and hydrochloric acid, the chlorin set free adds directly to the hydrocarbon and naphthalene tetra chloride is formed. The four chlorine atoms add to one of th rings.

Substitution products are formed when it is treated wit chlorine, bromine, nitric acid, or sulphuric acid. The opportu nities for isomerism are great owing to the presence of two rings For reference, the carbon atoms are numbered as follows:



Monosubstitution products exist in two forms. The carbon atoms numbered 1, 4, 5, and 8 bear the same relation to the molecule. Compounds which contain a group in these positions are usually called α-compounds. The atoms numbered 2, 3, 6, and 7 are alike; substitution in one of these positions yields β-compounds. Ten disubstitution products are possible in the case of compounds which contain two similar substituents; if the substituents are unlike, 14 disubstitution products are possible. The structure of a compound is shown by prefixing to its name numbers indicative of the positions occupied by the substituents.

When chlorine is passed into boiling naphthalene, α-chloronaphthalene (or 1-chloronaphthalene) is formed. The β-derivative is prepared by an indirect method. It will be recalled that when a substituent enters a benzene ring it takes a position ortho or para to the side chain if this is a hydrocarbon radical. In the case of naphthalene the α-position in one ring is ortho to the other ring and the β-position is meta. It is thus clear why β-derivatives are not readily formed by direct substitution. Nitric acid converts naphthalene in the cold into 1- or α-nitronaphthalene. At higher temperatures dinitronaphthalenes are formed which have the nitro groups in the 1, 8 and 1, 5 positions, the hydrogen atoms in the ortho position being replaced by the entering group.

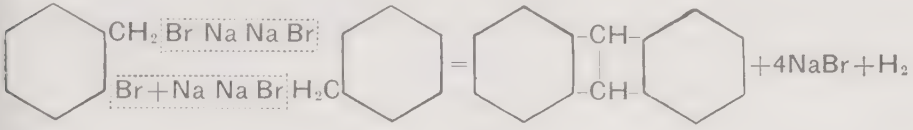
461. Anthracene, $C_{14}H_{10}$, is obtained from coal tar, in which it is present to the extent of less than 0.5 per cent. It is separated for use in the manufacture of dyes. Anthracene crystallizes in colorless plates, which show a blue fluorescence. It

melts at 218°, and boils at 342°. It forms an addition product with picric acid (trinitrophenol) of the formula

$$C_{14}H_{10}.(NO_2)_3C_6H_2OH$$

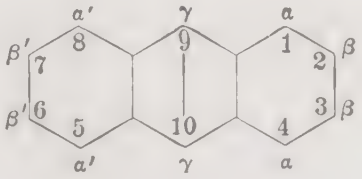
which melts at 138°. Certain other hydrocarbons form addition products with picric acid. The determination of the melting points of these compounds is frequently made as an aid in the identification of such hydrocarbons.

462. The *structure* assigned to anthracene is arrived at as the result of a number of syntheses of the hydrocarbon. When *o*-bromobenzyl bromide is heated with sodium, anthracene is formed:



Other important syntheses lead to the same conclusion as to the structure of anthracene, and the reactions of the hydrocarbon can be interpreted on the basis of this view.

463. *Chemical Properties.*—Anthracene is more reactive than benzene with reagents. It unites with two atoms of bromine at 0° and forms an addition product, anthracene dibromide, which readily loses hydrobromic acid and passes into monobromoanthracene. For reference, the carbon atoms of anthracene are numbered or indicated by Greek letters according to the following scheme:



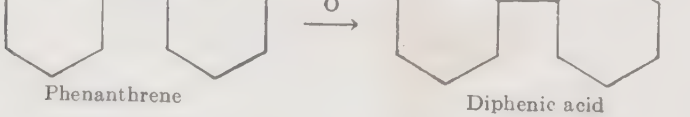
In anthracene dibromide, the bromine atoms are united to the carbon atoms numbered 9 and 10. When anthracene is treated with bromine at higher temperatures, substitution products which contain a number of halogen atoms are formed. Substitution takes place so readily with bromine that the reaction is conveniently used to prepare anhydrous hydrogen bromide, which is obtained by allowing bromine to fall, drop by drop, upon anthracene.

Anthracene yields sulphonic acids when treated with sulphuric acid. With nitric acid, however, nitro derivatives of the hydrocarbon are not formed. Anthracene is first oxidized to anthraquinone, $C_6H_4\begin{matrix}CO\\CO\end{matrix}C_6H_4$, which is converted into nitroanthraquinones if the acid used is concentrated or the mixture is heated. Oxidizing agents, in general, convert anthracene into anthraquinone, which crystallizes in light-yellow needles, melting at 285°.

464. Phenanthrene, $C_{14}H_{10}$, is an isomer of anthracene with which it occurs in coal tar. The fraction of the tar which contains phenanthrene contains also anthracene, carbazole,

$$C_6H_4\begin{matrix}|\\C_6H_4\end{matrix}\!\!>NH,$$

and other substances. The hydrocarbon is separated from anthracene by dissolving it from the mixture with carbon disulphide, in which anthracene is sparingly soluble. The product obtained by evaporation of the solvent is mixed with sodium hydroxide and distilled. The alkali converts the carbazole into a nonvolatile compound which is formed by the replacement by sodium of the hydrogen atom joined to nitrogen. Phenanthrene crystallizes in colorless lustrous plates, which yield fluorescent solutions. It melts at 99.6° and boils at 340.2°. The hydrocarbon resembles anthracene in its reactions. Oxidizing agents convert it into phenanthraquinone, which on further oxidation yields diphenic acid, a dicarboxylic acid derived from diphenyl. The formation of the latter is indicated by the following formulas:



Phenanthrene — Diphenic acid

Problems

1. Write equations for reactions to illustrate the following replacements in aromatic compounds: (*a*) H by Br, (*b*) H by CH_3, (*c*) H by SO_3H, (*d*) H by COOH, (*e*) COOH by H, (*f*) OH by H, (*g*) SO_3H by H.

2. Write equations for reactions by which the following may be prepared by the Fittig synthesis: (*a*) p-$CH_3C_6H_4C_3H_7$, (*b*) $C_6H_5C_3H_7$, (*c*) $C_6H_5CH_2$-$CH{=}CH_2$, (*d*) $C_6H_5C_6H_5$.

3. Write equations for reactions by which the following may be prepared by the Friedel-Crafts reaction: (*a*) $(C_6H_5)_2CH_2$, (*b*) p-$CH_3C_6H_4Cl$, (*c*) p-$NO_2C_6H_4COC_6H_5$, (*d*) $(C_6H_5)_2CCl_2$.

4. Show by equations how (*a*) $C_6H_5C_2H_5$ may be converted into C_6H_6; (*b*) $(C_6H_5)_2CO$ into $(C_6H_5)_2C{=}CH.CH_3$; (*c*) $(C_6H_5)_2CO$ into $(C_6H_5)_2C{=}C(C_6H_5)_2$; (*d*) $C_6H_5CH_3$ into $C_6H_5CH_2CH_2C_6H_5$; (*e*) $C_6H_5C_2H_5$ into $C_6H_5CH{=}CH_2$.

5. How could you distinguish by chemical means the following: (*a*) $C_2H_5C_6H_5$ and $(CH_3)_2C_6H_4$; (*b*) $C_6H_5C_2H_5$ and $C_6H_5CH{=}CH_2$; (*c*) C_6H_5-CH_3 and $C_5H_{11}CH_3$; (*d*) $C_6H_5COOCH_3$ and $CH_3COOC_6H_5$; (*e*) $C_6H_5SO_3H$ and $C_6H_{13}SO_3H$?

6. How could you separate by means of solvents the following: (*a*) C_6H_6 and $C_6H_5NO_2$; (*b*) C_6H_5Cl and $C_3H_7COOC_2H_5$; (*c*) C_6H_6 and C_3H_7OH; (*d*) $C_6H_5CH_3$ and $C_5H_{11}OH$; (*e*) C_6H_6 and C_6H_5COOH?

7. An aromatic hydrocarbon having the formula $C_{10}H_{14}$ yielded an acid $C_8H_6O_4$, when oxidized. Write three possible formulas for the hydrocarbon. How could you tell by synthesis which of the three formulas represented the structure of the hydrocarbon?

8. An aromatic compound having the formula $C_{13}H_{11}Cl$ was converted into $C_{13}H_9ClO$ on oxidation. Write possible formulas for the two compounds.

CHAPTER XIX

DETERMINATION OF THE STRUCTURE OF AROMATIC COMPOUNDS. NITRO COMPOUNDS AND SULPHONIC ACIDS

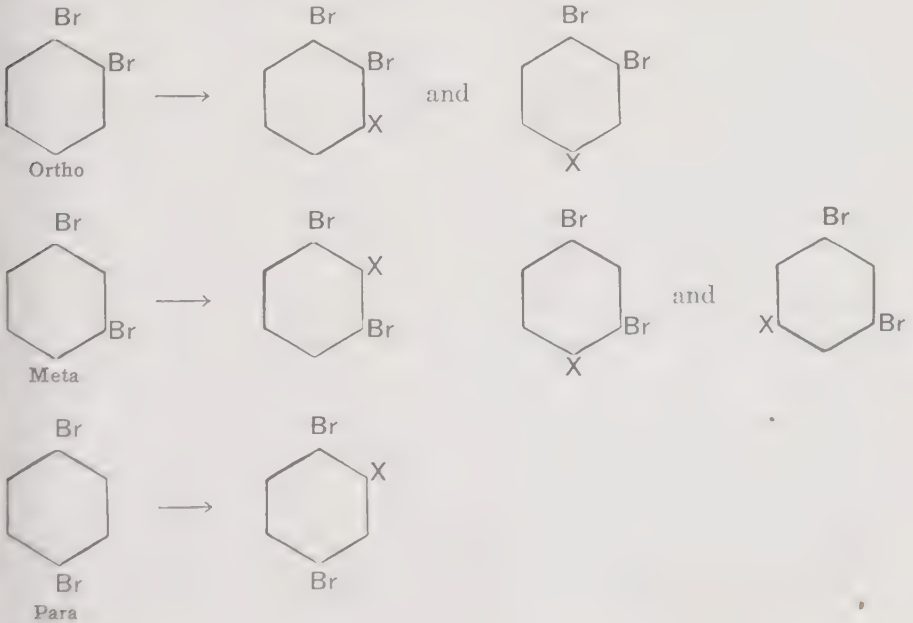
465. It has been stated that a number of isomeric derivatives of the aromatic compounds exist; from benzene can be obtained three dinitrobenzenes, three trinitrobenzenes, etc. It is well to indicate at the outset the general methods employed to determine the structure of such compounds, and thus avoid the frequent repetition which would result, if an attempt were made to state the arguments upon which the structure of each compound described is based.

When a new compound is prepared its structure is determined by converting it into one of known constitution. Thus, if a hydrocarbon yields on oxidation phthalic acid, a dicarboxylic acid derived from benzene by the replacement of two hydrogen atoms in the ortho position, the conclusion is drawn that the hydrocarbon contains two side chains in the ortho position. Again, if a substitution product of benzene is converted by simple reactions into metaxylene, the compound is considered to be a derivative of benzene in which the substituents occupy the meta position. The conclusions as to the structure reached in this way are based on two assumptions. It is assumed, first, that no deep-seated changes or molecular rearrangements take place in the transformations which are brought about, and the entering group takes the place of the group which it displaces; and, second, that the structure of the substance into which the new compound is converted is established. The first assumption is that upon which the determination of the structure of most organic compounds is based. It has been shown in the case of the aliphatic compounds that the assumption is a valid one in most cases, but that it leads to false conclusions at times. The same conclusion has been reached as a result of the study of aromatic compounds.

A noteworthy example of a case in which the method fails is furnished by the three isomeric bromobenzenesulphonic acids. The ortho, meta, and para compounds, when fused with sodium hydroxide, yield the same dihydroxy derivative of benzene, resorcinol, which has been shown to be a meta compound. On account of such facts as this, a definite conclusion as to structure cannot be reached by the study of a single transformation. The problem is not so difficult as it appears to be, on account of the fact that the exhaustive study of many transformations has shown clearly that those of certain types take place normally. Such transformations are the ones employed in the determination of structure.

The method which has been sketched can be used only when the structures of certain reference compounds are known. When the aromatic compounds were first studied it was necessary to establish by some absolute method the structure of a few compounds to which others might be referred. A number of ingenious methods were devised to solve this problem. But one of these, that of Körner, will be described here. The method is based on the determination of the number of monosubstitution products which can be obtained from the compound the structure of which is to be ascertained.

The application of the method to the three dibromobenzenes is evident from a consideration of the following formulas:



Of the three dibromobenzenes the one which yields two monosubstitution products has the *ortho* structure; the one that yields three is the *meta* compound; and the one that yields but one is the *para*.

The dibromobenzenes serve as reference compounds in determining the structure of other substances. Thus, each can be converted into a xylene, $C_6H_4(CH_3)_2$, by the replacement of the bromine atoms by methyl radicals; the ortho compound yields orthoxylene, etc. Knowing the structure of the xylenes it is possible to determine the structure of the acids formed when they are oxidized; the phthalic acid, $C_6H_4(COOH)_2$, obtained in this way from orthoxylene is the *ortho* compound. It is readily seen how this method can be applied to the determination of the structure of a large number of compounds.

Influence of the Nature of the Radicals Present in a Compound on the Position Taken by Substituents

466. From a study of the structure of many substances formed as the result of the introduction of substituents into aromatic compounds, certain general conclusions of great importance can be drawn. It has been pointed out that aromatic compounds yield substitution products when treated with sulphuric acid, nitric acid, chlorine, and bromine. Under certain conditions iodine can also be introduced directly. Alkyl, acyl, and other radicals can be introduced by means of the Friedel and Crafts synthesis. In all these cases the position in the molecule taken by the entering atom or group is determined by the nature of the atom or group already present. The facts established lead to the following rules:

I. If the compound contains OH, NH_2, F, Cl, Br, I, or a hydrocarbon radical (CH_3, C_6H_5, etc.), the entering atom or group, Cl, Br, I, SO_3H, NO_2, alkyl radical (CH_3), or acyl radical (CH_3CO) enters the positions para and ortho to the group already present. In general, the proportion of the para compound formed is greater than that of the ortho compound. In most cases a small proportion of the meta compound is formed.

II. If the compound contains COOH, SO_3H, NO_2, CN, CHO, or COR, the entering atom or group takes the position meta to

the group already present. At the same time a small proportion of the ortho and para compounds is also formed.

467. It should be noted that certain classes of compounds yield para and ortho compounds, and others yield principally meta compounds. Groups which send an entering substituent to the *meta* position all contain a negative atom (oxygen, nitrogen, or halogen) in combination with the atom in these groups that is joined to the benzene ring; this is not so in the case of the groups that cause substitution in the *ortho* and *para* positions.

468. When substitution takes place, the relation between the amounts of the isomers formed is influenced by (1) the group present, (2) the group introduced, (3) the temperature, and (4) the catalyst, if one is used. (1) In the classification given above all the groups in the first division send an entering element or radical to the para and ortho positions, but the groups differ among themselves in their effect on the relative proportion of the two isomers formed. For example, when fluorobenzene and chlorobenzene are nitrated at 0°, the mixture of ortho and para nitro derivatives obtained contains in the first case 12.4 per cent and in the second, 30.1 per cent of the ortho compound. (2) While the group present determines the position taken by the entering group whatever the nature of the latter may be, the proportion of the isomers formed is changed as the entering substituent is changed. Thus, phenol, C_6H_5OH, when chlorinated at 90° gives 50.2 per cent of parachlorophenol and 49.8 per cent of the ortho compound; under the same conditions bromine yields 90.7 per cent of para- and 9.3 per cent of ortho-bromophenol. (3) The temperature at which substitution takes place markedly affects the proportion of the isomers formed in the case of sulphonation; low temperature favors, in general, the production of the ortho compound. (4) When different catalysts are used to promote the reaction different results are obtained. For example, in the chlorination of chlorobenzene with aluminium chloride as catalyst the percentages of the ortho, meta, and para derivatives formed were, respectively, as follows: 29.6, 4.7, and 65.7. When an equivalent weight of ferric chloride was used the percentages were as follows: 39.2, 5.3, 55.5. It is probable that the three reactions that lead to the formation of the three isomers are taking place simultaneously, and that the catalyst used affects differently the rates at which they proceed. The factors that influence the results obtained when substitution in aromatic hydrocarbons takes place have been studied in some detail, but much remains to be done in connection with the investigation of this important type of reaction.

Nitro Compounds

469. Preparation of Nitro Compounds.—The nitro derivatives of the aromatic compounds are prepared by the action of nitric

acid on the hydrocarbons or their substitution products. The process is called *nitration*. The ease with which reaction takes place is determined by the nature of the element or group in combination with the benzene ring. In general, it is more difficult to nitrate a compound which contains a *meta*-orienting substituent than one which contains alkyl, hydroxyl, or amino groups. For example, benzoic acid, $C_6H_5.COOH$, must be heated with either fuming nitric acid, or a mixture of concentrated nitric acid and sulphuric acid, in order to convert it into nitrobenzoic acid. On the other hand, phenol, C_6H_5OH, can be nitrated by allowing it to react at ordinary temperatures with concentrated nitric acid diluted with twice its volume of water.

The number of nitro groups introduced is determined by the strength of the acid used, and the temperature at which the reaction is carried out. As the number of these groups increases, the difficulty of further nitration also increases.

Hydrocarbons are usually nitrated by treating them with a mixture of concentrated nitric and sulphuric acids. Since the reaction involves the formation of water

$$C_6H_6 + HNO_3 = C_6H_5NO_2 + H_2O$$

the acid becomes more and more dilute as the nitro compound is formed, and finally ceases to act. This difficulty is overcome by adding to the mixture concentrated sulphuric acid, which unites with the water formed and thus prevents the dilution of the nitric acid.

The nitro derivatives of benzene and its homologues are pale-yellow liquids which distill without decomposition, or colorless or yellow solids which crystallize well. They are heavier than water, in which they are insoluble. They are soluble in alcohol and in ether. Solid nitro compounds are often prepared and their melting points determined as an aid in the identification of other substances.

Nitro derivatives of certain aromatic hydrocarbons are manufactured commercially in large quantities and are used in the preparation of amines which are converted into a great variety of dyes.

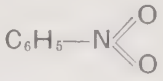
470. Reactions of Nitro Compounds.—Nitro compounds are reduced to amines by nascent hydrogen in acid solution:

$$C_6H_5NO_2 + 6H = C_6H_5NH_2 + 2H_2O$$

In the laboratory the reduction is usually effected by treating the nitro compound with tin and hydrochloric acid. In alkaline solution, nitro compounds are reduced to azoxy, azo, and hydrazo compounds, which will be described later (**519**).

Nitro derivatives are, in general, stable compounds, from which the nitrogen is removed with difficulty. The accumulation of nitro groups, however, has a marked effect on the reactivity of the nitro groups or the other atoms or groups which the compound contains.

The fact that nitro compounds are converted by reduction into amines is evidence that in the nitro compounds the nitrogen atom is joined to the ring. The structure of nitrobenzene is accordingly



471. Nitrobenzene, $C_6H_5NO_2$, is a yellow liquid, which has an odor resembling that of the oil of bitter almonds; it boils at 210.9°, melts at 5.7°, and has the specific gravity $1.207^{20°}_{4°}$. It is manufactured in large quantities by allowing a mixture of nitric acid and sulphuric acid to flow slowly into benzene which is kept cool and thoroughly stirred. Nitrobenzene is converted into aniline, $C_6H_5NH_2$, by nascent hydrogen. It is soluble in concentrated sulphuric acid, and is precipitated unchanged when the solution is diluted with water.

472. Dinitrobenzenes, $C_6H_4(NO_2)_2$, are formed when benzene is heated with a mixture of nitric acid and sulphuric acid. The chief product of the reaction is *m*-dinitrobenzene, which crystallizes from alcohol in colorless needles, melts at 89.7° and boils at 302°. *o*-Dinitrobenzene and *p*-dinitrobenzene, which melt at 116.5° and 172°, respectively, are also formed in small quantities.

The three dinitrobenzenes yield diamines, $C_6H_4(NH_2)_2$, when reduced by the hydrogen generated by the action of an acid on a metal. Under certain conditions, which will be discussed

later (620), but one nitro group can be reduced. In this way nitroanilines may be prepared:

$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + 6H = C_6H_4\begin{matrix}NO_2\\NH_2\end{matrix} + 2H_2O$$

473. The introduction of a second nitro group into nitrobenzene increases the reactivity of the compound with various reagents. The position occupied by the second group has a marked effect on the reactivity of the resulting compound. The nitro groups in *m*-dinitrobenzene are firmly bound to the ring, and as a consequence are not readily removed by reagents. The hydrogen atom situated between the two nitro groups is, however, rendered more active as it is oxidized to a hydroxyl group when *m*-dinitrobenzene is treated with potassium ferricyanide. The compound formed is 2, 6,-dinitrophenol. One of the nitro groups in *o*-dinitrobenzene and in *p*-dinitrobenzene can be removed by certain reagents. Both compounds are converted into ethers when treated with sodium methylate:

$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + NaOCH_3 = C_6H_4\begin{matrix}OCH_3\\NO_2\end{matrix} + NaNO_2.$$

The ortho compound is more reactive than the para compound. When the former is boiled with a solution of sodium hydroxide, one nitro group is replaced by hydroxyl, and when heated with an alcoholic solution of ammonia, by the amino group:

$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + NaOH = C_6H_4\begin{matrix}OH\\NO_2\end{matrix} + NaNO_2$$

$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + NH_3 = C_6H_4\begin{matrix}NH_2\\NO_2\end{matrix} + HNO_2$$

Similar reactions are observed in other cases. In general, the influence of a group on a second group decreases as we pass from the ortho to the para to the meta positions, the effect of a group in the ortho position being much greater than that of a group in the other positions.

474. Nitrotoluenes, $C_6H_4(CH_3)(NO_2)$, are formed when toluene is nitrated. When nitration is carried out at 0° the resulting product consists of 36.8 per cent of *p*-nitrotoluene (m.p. 51.3°, b.p. 238°), 58.8 per cent of *o*-nitrotoluene (m.p. −10.6°, b.p. 222.3°), and 4.4 per cent of the meta compound (m.p. 15.5°, b.p. 231°). The relation between the amounts of each formed is determined by the temperature at which the nitration is effected. In general, the temperature has an appreciable effect on the position taken by an entering group, when substitution is effected.

Symmetrical trinitrotoluene ("T.N.T."), $C_6H_3(CH_3)(NO_2)_3$, was used extensively as a high explosive during the World War (606). It was prepared by converting toluene successively into the mono-, di-, and tri-nitro derivative. By proceeding in this way there was a marked saving in the amount of nitric acid required, and the product obtained was in a purer condition as it contained smaller amounts of other nitrotoluenes, the presence of which rendered the compound less stable.

475. Nitrostyrene, $C_6H_5CH=CHNO_2$, contains the nitro group in the side chain. It is prepared by the action of nitric acid on styrene, the reaction being an example of the few cases in which a nitro group is introduced into a side chain by direct nitration. The nitrostyrenes in which the substituent is situated in the ring are prepared from compounds into which the nitro group has been introduced before the double bond is established.

476. *o*-Nitrophenylacetylene, $NO_2C_6H_4.C\equiv CH$, is prepared by boiling *o*-nitrophenylpropiolic acid with water:

$$NO_2C_6H_4.C\equiv C.COOH = NO_2C_6H_4.C\equiv CH + CO_2$$

The method of preparation is illustrative of the methods usually employed to prepare derivatives of hydrocarbons which contain unsaturated side chains. The derivatives are usually not prepared directly from the hydrocarbons, as in the case of benzene and its homologues, but a saturated compound which contains the substituent in the desired position is first formed and then converted into an unsaturated compound by the usual methods.

477. α-Nitronaphthalene, $C_{10}H_7.NO_2$, is formed as the result of the direct nitration of naphthalene. It crystallizes in yellow prisms, which melt at 58.8°. The β-compound (2-nitronaphthalene), which melts at 79°, is prepared by an indirect method.

478. Identification of Nitro Compounds.—The definite identification of a substance as a nitro compound is difficult, as substances exist which are closely related to nitro compounds and show many of the reactions of the latter. Nitro compounds are insoluble in water, but dissolve in many organic solvents. They are, in general, soluble without decomposition in concentrated sulphuric acid and are precipitated when the solution is poured into water. The specific gravity of nitro compounds is greater than one. When treated with tin and hydrochloric acid,

they are reduced to amines. This reaction serves as a valuable test. The nitro compound, which is insoluble in hydrochloric acid, is converted into a salt of an amine, which is soluble. A mixture of stannous chloride and hydrochloric acid may be used conveniently in making the test, as nitro compounds are reduced by this reagent. When a nitro compound is warmed with stannous chloride and hydrochloric acid, it passes into solution slowly, owing to the formation of the hydrochloride of the amine:

$$C_6H_5NO_2 + 3SnCl_2 + 7HCl = C_6H_5NH_2.HCl + 3SnCl_4 + 2H_2O$$

The amine is liberated from its salt by treating the solution with an excess of sodium hydroxide, and may be obtained by extracting with ether or distilling with steam.

It should be noted that nitro compounds containing other groups often possess properties which are not characteristic of simple nitro compounds. For example, nitrobenzene is insoluble in a solution of sodium hydroxide, but nitrophenol, $NO_2.C_6H_4OH$, is soluble in this reagent. The difficulty met with in the identification of such compounds is consequently greater than that encountered in the case of substances which contain but one kind of substituent.

Sulphonic Acids

479. Preparation of Sulphonic Acids.—Sulphonic acids are prepared by the action of concentrated sulphuric acid on aromatic compounds:

$$C_6H_6 + H_2SO_4 = C_6H_5.SO_3H + H_2O$$

When sulphonation takes place with difficulty, it is necessary to use a mixture of sulphuric acid and sulphur trioxide, the proportion of the latter being determined by the difficulty with which the sulphonic acid group is introduced. The nature of the substituent in the benzene ring affects markedly the ease with which sulphonation is effected. The statement made in connection with the nitro compounds applies to sulphonation as well as to nitration.

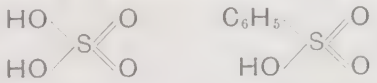
The sulphonic acids are solids that crystallize from water, in which many are readily soluble. In order to isolate them they must be separated from the excess of sulphuric acid present in the mixture obtained as the result of sulphonation. This

can be done in a number of ways. The simplest method, which is applicable in a number of cases, is to pour the mixture into concentrated hydrochloric acid. Many sulphonic acids which are readily soluble in water, dissolve with difficulty in concentrated hydrochloric acid. The precipitate formed is filtered off, washed with hydrochloric acid until free from sulphuric acid, and finally crystallized from water. If the sulphonic acid is difficultly soluble in water, it is separated from the excess of sulphuric acid by pouring the product of the reaction into ice water.

Oftentimes it is advisable to isolate the sulphonic acid as a salt. One way of doing this is to pour slowly the mixture of sulphonic acid and sulphuric acid into a saturated solution of sodium chloride, which is kept cold. The sodium salt of the sulphonic acid separates, owing to its insolubility in a solution of sodium chloride. The salts prepared in this way always are contaminated by sodium chloride.

A second method of isolating a salt of the acid, which is applicable in all cases, is based on the facts that the barium salts of sulphonic acids are soluble in water, whereas barium sulphate is insoluble. The mixture of sulphuric acid and sulphonic acid is diluted with water and neutralized with barium carbonate. The solution is then heated and filtered. On evaporation the barium salt of the sulphonic acid is obtained. The free acid may be prepared by adding to a solution of the barium salt the amount of sulphuric acid required to precipitate the barium as sulphate.

480. Reactions of Sulphonic Acids.—The sulphonic acids are strong acids and resemble sulphuric acid in many of their properties. They are considered as derived from sulphuric acid by the replacement of a hydroxyl group by a radical:



The reactions of sulphonic acids are in accord with this view of their structure. When subjected to the action of active reducing agents they are converted into mercaptans, in which the sulphur is joined to carbon:

$$C_6H_5.SO_3H \xrightarrow{H} C_6H_5.SH$$

Sulphonic acids react with alcohols and form esters

$$C_6H_5SO_2.OH + C_2H_5OH = C_6H_5SO_2.OC_2H_5 + H_2O$$

which show the chemical properties characteristic of other esters.

When treated with phosphorus pentachloride, sulphonic acids or their salts are converted into acyl chlorides:

$$C_6H_5SO_2OH + PCl_5 = C_6H_5SO_2Cl + POCl_3 + HCl$$

When sulphonic acids are heated under pressure with water the sulphonic group is eliminated and hydrocarbons are formed:

$$CH_3.C_6H_4.SO_3H + HOH = CH_3.C_6H_5 + H_2SO_4$$

The salts of sulphonic acids are frequently used in the preparation of other compounds, as the sulphonic acid group can be replaced by other groups. When fused with sodium or potassium hydroxide, the salts of sulphonic acids are converted into the salts of phenols:

$$C_6H_5SO_3K + 2KOH = C_6H_5OK + K_2SO_3 + H_2O$$

The free phenols are obtained by adding acid to the product of the reaction:

$$C_6H_5OK + HCl = C_6H_5OH + KCl$$

This reaction, which furnishes a convenient way of converting a hydrocarbon into its hydroxyl derivative, is used in the industrial preparation of phenol and analogous compounds.

When a salt of a sulphonic acid is distilled with potassium cyanide, a nitrile is formed:

$$C_6H_5SO_3K + KCN = C_6H_5CN + K_2SO_3$$

This reaction furnishes a means of preparing cyanides, from which acids are obtained by hydrolysis.

481. Benzenesulphonic acid, $C_6H_5SO_3H.1\frac{1}{2}H_2O$, forms deliquescent crystals, which are very soluble in water, and melt at 46°. The acid can be converted into phenol, C_6H_5OH, benzonitrile, C_6H_5CN, and benzenesulphonyl chloride, $C_6H_5SO_2Cl$, as described above.

482. Benzenesulphonyl chloride, $C_6H_5SO_2Cl$, is an oil, insoluble in water, which possesses a characteristic odor. It boils with decomposition at 247° but distills unchanged at 120° under a pressure of 10 mm. It solidifies in a freezing mixture to crystals which melt at 14.5°. The compound possesses the chemical properties which are characteristic of acyl chlorides. It is decom

posed slowly by hot water, reacts with alcohols to form esters, and with ammonia and amines to form amides.

Benzenesulphonyl chloride is a useful reagent to distinguish between the three classes of amines. The method was first described by Hinsberg. When a primary amine is treated with the chloride in the presence of sodium hydroxide, a substituted sulphonamide is formed:

$$C_6H_5SO_2Cl + CH_3NH_2 = C_6H_5SO_2.NHCH_3 + HCl$$

The compound is soluble in sodium hydroxide:

$$C_6H_5SO_2NHCH_3 + NaOH = C_6H_5SO_2NNaCH_3 + H_2O$$

An amide is formed also when the chloride reacts with a secondary amine:

$$C_6H_5SO_2Cl + (CH_3)_2NH = C_6H_5SO_2.N(CH_3)_2 + HCl$$

but the resulting product is not soluble in alkalies as it contains no hydrogen atom which can be replaced by a metallic atom. Tertiary amines do not react with benzenesulphonyl chloride. It is thus possible to separate and distinguish from one another the three classes of amines.

483. Benzenesulphonamide, $C_6H_5SO_2NH_2$, is formed by the action of ammonia on benzenesulphonyl chloride. It crystallizes from hot water in needles which melt at 156°. It shows the chemical properties characteristic of amides. On account of the presence of the $C_6H_5SO_2$ group, the amide dissolves in aqueous solutions of sodium hydroxide with the resulting formation of a salt, $C_6H_5SO_2NHNa$. When a solution of this salt is treated with sodium hypochlorite a chloro-amide is formed: $C_6H_5SO_2NCl_2$ (*cf.* Sec. **290**). Analogous derivatives of toluenesulphonamide are used as antiseptics: *chloramine-T* has the formula p-$CH_3C_6H_4$-$SO_2NClNa.3H_2O$ and *dichloramine-T*, p-$CH_3C_6H_4SO_2NCl_2$.

The amides prepared from sulphonic acids crystallize well from hot water and possess well-defined melting points. They are, as a consequence, of service in effecting the identification of sulphonic acids.

484. Toluenesulphonic Acids, $CH_3C_6H_4.SO_3H$.—The product of the reaction between toluene and sulphuric acid consists almost entirely of a mixture of the para and ortho acids. The relation between the amounts of the two acids formed is affected

by the temperature at which the reaction is carried out. Whe a mixture of sulphuric acid and toluene is heated on a wate bath, the chief product is the para acid. When the mixture i kept at room temperature and stirred vigorously the percentag of the ortho compound formed is largely increased.

485. Naphthalenesulphonic Acids, $C_{10}H_7.SO_3H$.—The effec of the temperature at which sulphonation is carried out on th position taken by the entering group is well shown in the case o naphthalene. When the hydrocarbon is heated with concen trated sulphuric acid at 80°, the chief product of the reaction i the 1- or α-acid; at 160° the 2- or β-acid is chiefly formed. Th acids form hygroscopic crystals. They are prepared in large quan tities in the manufacture of the naphthols and the naphthylamines

486. Identification of Sulphonic Acids.—In order to deter mine whether a substance which contains sulphur is a sulphoni acid or a salt of a sulphonic acid, it is fused with potassium hydroxide for a short time, care being taken to avoid heating to a higher temperature than is necessary to fuse the alkali The product is next dissolved in water, and a slight excess of dilute acid is added. If the substance used is a sulphonic acid a phenol and sulphur dioxide are formed. The presence of a phenol in solution can be determined by adding bromine water as phenols are converted into insoluble bromine substitution products when treated with an aqueous solution of the halogen The presence of sulphur dioxide, which is formed from the sulphite produced as the result of the fusion with the alkali, can be detected by its odor.

If the compound proves to be a sulphonic acid, its identi fication is completed by converting it into a sulphonamide, the melting point of which is determined. The acid or salt is treated with phosphorus pentachloride, and the resulting sulphonyl chloride, after washing with water, converted into the amide by allowing it to stand for a short time with ammonia. The amide is finally crystallized from hot water.

Problems

1. Two hydrocarbons of the formula C_9H_{12} were studied. One yielded two and the other three mononitro derivatives. Write the structural formulas of the two hydrocarbons and the nitro derivatives.

2. Write the structural formula of the hydrocarbon $C_{12}H_{18}$ which yielded but one mononitro compound and was converted by oxidation into the acid $C_8H_6O_4$.

3. Write the graphic formulas of the dibromo derivatives of the following hydrocarbons, the halogen being either in the side chain, ring, or in both: (*a*) *o*-$(CH_3)_2C_6H_4$; (*b*) *m*-$(CH_3)_2C_6H_4$; (*c*) *p*-$(CH_3)_2C_6H_4$.

4. Applying the rules for substitution in aromatic compounds, write the graphic formulas of the compounds formed when one and two nitro groups are introduced into the following: (*a*) $CH_3C_6H_5$; (*b*) *p*-$(CH_3)_2C_6H_4$; (*c*) $C_6H_5NO_2$; (*d*) C_6H_5OH; (*e*) *o*-$NO_2C_6H_4OH$; (*f*). *p*-$NO_2C_6H_4OH$.

5. Starting with benzene write reactions by which the following may be prepared: (*a*) *p*-$BrC_6H_4NO_2$; (*b*) *m*-$BrC_6H_4NO_2$; (*c*) *o*-$BrC_6H_4NO_2$; (*d*) *p*-$NO_2C_6H_4COOH$; (*e*) *m*-$NO_2C_6H_4COOH$.

6. (*a*) How could you determine the percentage of sulphuric acid in a mixture of the acid with benzenesulphonic acid? (*b*) How could you obtain the latter acid free from sulphuric acid?

7. Write the formulas of the compounds you would expect as oxidation products of the following: (*a*) cymene, (*b*) diphenylmethane, (*c*) tetraphenylethylene, (*d*) styrene, (*e*) diphenyl, (*f*) 1-nitronaphthalene.

8. Show how by the use of solvents a mixture of the following may be separated: C_6H_6, $CH_3C_6H_4COOH$, $C_6H_5NO_2$, and $(CH_3)_2CO$.

CHAPTER XX

HALOGEN DERIVATIVES OF AROMATIC HYDROCARBONS

487. It will be recalled that the halogen substitution products of the aliphatic compounds are prepared in general from oxygen derivatives or from unsaturated compounds. While halogen derivatives are also formed as the result of the substitution of halogen for hydrogen by the direct action of chlorine or bromine, the preparation of compounds in this way is effected most conveniently in a comparatively few cases only. The most generally applicable method of preparing halogen derivatives of the aromatic compounds, however, is by the action of the free halogen on hydrocarbons or their substitution products.

Preparation of Halogen Compounds.—Many aromatic compounds like toluene, xylene, benzyl alcohol, $C_6H_5.CH_2OH$, etc., contain, in addition to a benzene ring, a radical related to the aliphatic compounds. The methods employed to introduce halogen into these side chains are the same as those used in the case of the derivatives of methane. Benzyl alcohol, C_6H_5-CH_2OH, for example, may be considered as a substitution product of methyl alcohol formed as the result of the replacement of one hydrogen atom by the phenyl radical. The hydroxyl group which it contains is linked to a methane carbon atom. In order to replace the hydroxyl group by bromine, the method used is that by which methyl alcohol is converted into methyl bromide, namely, the treatment of the alcohol with hydrobromic acid. In phenol, $C_6H_5.OH$, on the other hand, the hydroxyl group is linked to a carbon atom in the benzene ring and, as a consequence, is not replaced by bromine when phenol is treated with hydrobromic acid. It should be noted, therefore, that the selection of the method to be used to introduce halogen atoms into an aromatic compound is determined by the place in the molecule which the atom is to enter. If the halogen is to be

introduced into the side chain, the various methods described under aliphatic halogen derivatives may be used; if it is to be introduced into the ring, the methods about to be considered should be used.

Substitution of hydrogen in the benzene ring is readily effected by chlorine or bromine. The ease with which reaction takes place is determined by the nature of the group present in the compound. In general, the effect of the various groups on the introduction of halogen is the same as that mentioned in the case of nitration. For example, phenol, C_6H_5OH, and aniline, $C_6H_5NH_2$, are converted into bromine substitution products when treated with an aqueous solution of the halogen. In the case of hydrocarbons and compounds which contain meta-orienting groups the introduction of halogen is much facilitated by the presence of a carrier. Iron or iodine is most frequently used for this purpose.

488. The position taken by halogen atoms in the derivatives of benzene which contain alkyl radicals as side chains is markedly affected by the conditions under which the reaction takes place. At low temperatures, if reaction takes place, the halogen replaces the hydrogen atoms in the ring. *When*, however, *chlorine or bromine is passed into the boiling hydrocarbon, the halogen enters the side chain. In the presence of a halogen carrier substitution takes place almost exclusively in the ring*, or nucleus, as it is sometimes called. The effect of sunlight on the reaction is also marked. It will be recalled that sunlight facilitates greatly the replacement of hydrogen by halogen in aliphatic compounds. A similar effect is observed in the case of aromatic compounds which contain aliphatic side chains. Even at 0° *chlorine or bromine enters the side chain when the reaction takes place in the sunlight.*

The principles which have just been stated are of great importance. They are emphasized by the following example. When a mixture of toluene and bromine is allowed to stand at a low temperature in the dark, substitution takes place slowly and *p*-bromotoluene and *o*-bromotoluene, $C_6H_4Br.CH_3$, are formed. When, however, bromine is added to boiling toluene, substitution in the side chain takes place and compounds of the formulas $C_6H_5.CH_2Br$, $C_6H_5.CHBr_2$ and $C_6H_5.CBr_3$ are formed. The

presence of a carrier increases the rate at which substitution in the ring takes place.

489. Iodine can be introduced into aromatic compounds by the action of the free halogen, if the reaction is carried out under conditions which bring about the removal of the hydriodic acid formed as the result of the substitution. For example, iodobenzene is formed when benzene is heated with iodine and nitric acid, mercuric oxide, iodic acid, or other substances which react with hydriodic acid. Reactions of this kind are used in a limited number of cases only as a means of preparing iodo derivatives. Free iodine also converts aniline, $C_6H_5.NH_2$, into substitution products. In this case the hydriodic acid formed is removed as the result of the formation of a salt of aniline, $C_6H_5NH_2.HI$.

Halogen derivatives of aromatic compounds may also be prepared from hydroxyl derivatives by a reaction which is analogous to that used in the case of aliphatic compounds. When phenol, C_6H_5OH, and similar substances are treated with the halides of phosphorus, the hydroxyl groups are replaced by halogen. The yield of halogen compound is small in most cases, however, and the reaction is seldom used as a means of preparing such compounds. When the hydroxyl group is situated in a side chain, the reaction takes place, in the main, as in the case of aliphatic compounds.

Halogen derivatives which contain the halogen joined to the ring are conveniently prepared from amino compounds. The method of preparation, which is an important one on account of its wide applicability, will be described in detail later (**527**). It involves the conversion of an amine, for example, aniline, $C_6H_5NH_2$ into a diazonium compound, $C_6H_5N_2Cl$, which, when heated with the hydrogen halides or certain of their salts, undergoes decomposition with the formation of a halogen derivative. The following equation expresses such a decomposition:

$$C_6H_5N_2Cl + KI = C_6H_5I + N_2 + KCl$$

In this way the NH_2 group may be replaced by chlorine, bromine, or iodine. As amino compounds are readily prepared from nitro compounds, which, in turn, are formed by the action of nitric acid on hydrocarbons, the reaction serves as a means of introducing halogen atoms into hydrocarbons. Although a number of steps is involved in the process, it is often used in the prepa-

ration of halogen derivatives. It is of particular value in the preparation of iodo compounds and of halogen derivatives which cannot be prepared by the direct action of halogens on hydrocarbons. The use of the diazo reaction in the preparation of halogen compounds will be illustrated by typical examples later.

The number of halogen atoms introduced into the ring by direct chlorination or bromination is determined by the amount of the halogen used, and the temperature at which the reaction is carried out. The position taken by the entering atom is determined by the nature of the groups present. The conclusions which have been arrived at, as the result of the study of many compounds, have been summarized in the rules which have been given (**466**).

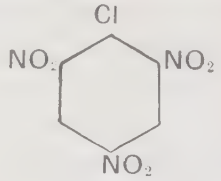
Physical Properties.—The halogen derivatives of the aromatic hydrocarbons are liquids or solids of comparatively high boiling points. Those in which the substituent is in the ring have faint, agreeable odors, while those which contain halogen atoms in the side chain have generally a pungent odor. In many cases they cause a copious flow of tears. The acyl halides derived from the aromatic acids resemble in properties the halides of the fatty acids. They will be discussed in connection with the acids.

490. Reactions of Aromatic Halogen Compounds.—The ability of a halogen atom in an aromatic compound to react with other substances is dependent upon its position in the molecule and upon the nature and the relative position of the other atoms or groups present. *Halogen atoms in side chains show the reactions which are characteristic of aliphatic compounds.* Thus benzyl chloride, $C_6H_5.CH_2Cl$, can be converted by water into benzyl alcohol, $C_6H_5.CH_2OH$; by potassium sulphite into a sulphonic acid, $C_6H_5CH_2.SO_3H$; etc. *Halogen atoms in the nucleus, in general, do not enter into reaction readily.* Chlorobenzene, for example, is not affected by boiling alkalies, acid sulphites, potassium cyanide, ammonia, and many of the other substances which react with aliphatic halogen compounds. The halogen atoms in chlorobenzene and similar compounds are removed by sodium, however. The formation of biphenyl from bromobenzene has already been noted:

$$2C_6H_5Br + 2Na = C_6H_5.C_6H_5 + 2NaBr$$

Magnesium also reacts with halogen compounds in which the halogen atom is in the ring. Bromobenzene and the metal yield the compound C_6H_5MgBr, which can be used in the preparation of a large number of substances by Grignard's method.

The accumulation of meta-orienting groups in a halogen compound results in an increased activity of the halogen atom. This is especially noticeable in the case of the compounds in which two nitro groups are situated in the positions ortho to a halogen atom. The trinitrochlorobenzene of the structure



for example, reacts readily with hot water, and the halogen atom is replaced by a hydroxyl group. The compound resembles in many of its reactions the acyl chlorides.

491. Identification of Aromatic Halogen Compounds.—The methods of identifying these compounds are similar to those described under the aliphatic compounds. It is often possible to determine whether the halogen present is in the ring or in the side chain by boiling the substance to be tested with an alcoholic solution of potassium hydroxide. If no reaction takes place it can be assumed that the halogen atom present is in combination with a carbon atom in the ring. In order to determine whether or not reaction has taken place, the product is poured into water, acidified with nitric acid, and silver nitrate is added. The formation of a precipitate of a silver halide shows that the halogen has been removed from the organic compound.

The chlorides derived from the aromatic acids, of which benzoyl chloride, $C_6H_5.COCl$, is an example, do not react rapidly with water. They are readily converted into salts when shaken with a solution of an alkali, and into esters when shaken with ethyl alcohol and a solution of sodium hydroxide. The identification of acyl chlorides is best effected by converting them into amides by the action of ammonia:

$$C_6H_5COCl + NH_3 = C_6H_5CONH_2 + HCl$$

A few typical halogen substitution products will now be described briefly.

492. Bromobenzene, C_6H_5Br, is prepared by the action of bromine on benzene. It is a colorless liquid which boils at 156.2°, and has the specific gravity $1.497^{20°}_{4°}$. The effect of a halogen carrier on the rate at which substitution takes place can be readily shown by treating two samples of benzene with bromine and adding to one a small amount of aluminium or powdered iron. No appreciable reaction takes place for a long time in the mixture which does not contain the carrier. In the presence of the metal, however, substitution soon takes place and hydrobromic acid is rapidly evolved. If the mixture of bromine and benzene which contains a carrier is heated, some dibromobenzene is formed, although the amount of the halogen used is that which corresponds to the amount required for the introduction of a single halogen atom. Even when the greatest precautions are taken, it is impossible to exclude the formation of the disubstitution product. The latter can be partially separated from bromobenzene by distillation with steam, with which bromobenzene is more volatile than dibromobenzene. The substance is finally purified by fractional distillation.

493. Dibromobenzenes, $C_6H_4Br_2$.—When two bromine atoms are introduced into benzene by direct substitution, the chief product of the reaction is the para compound, which melts at 86.8° and boils at 219°. A small amount of the ortho compound is also obtained; this melts at 1.8° and boils at 221°. *m*-Dibromobenzene is most conveniently made by an application of the diazo reaction (**527**). The most readily prepared dinitrobenzene is a meta compound, on account of the fact that a nitro group directs an entering group to the meta position. For this reason, nitro compounds are much used in the preparation of substitution products which contain substituents in the meta positions. Nitro compounds can be readily reduced to amines, and these, in turn, can be converted into halogen compounds by replacing the amino group by means of the diazo reaction. *m*-Dibromobenzene melts at −6.9° and boils at 217°. The structure of the dibromobenzenes has been determined by converting them into the xylenes, which, it has been pointed out, serve as reference compounds.

All the possible bromine substitution products of benzene are known. Hexabromobenzene, C_6Br_6, is formed by the action

of bromine on benzene in the presence of iodine at 250° to 400°. It is a solid which melts at about 306°.

494. Iodobenzene, C_6H_5I, is most readily prepared from aniline, $C_6H_5NH_2$, by the diazo reaction. It boils at 188.6°. The compound, like other aromatic iodo derivatives, enters into reactions which are not shown by halogen derivatives which contain chloride or bromine. These reactions result from the fact that iodine can form stable compounds in which the valence of the halogen is greater than one. It will be recalled that when iodine is treated with chlorine, iodine trichloride, ICl_3, is formed. Iodine in aromatic compounds also shows the ability to unite with chlorine. When chlorine is passed into a solution of iodobenzene in chloroform, a yellow crystalline precipitate of phenyliodochloride, $C_6H_5ICl_2$, is formed. When this compound is treated with potassium hydroxide it is converted into iodosobenzene, C_6H_5IO, which, on boiling with water, undergoes decomposition according to the following equation:

$$2C_6H_5IO = C_6H_5I + C_6H_5IO_2$$

Phenyl iodide and iodoxybenzene are formed. The latter, as well as iodosobenzene, is an explosive compound.

When a mixture of iodosobenzene and iodoxybenzene is shaken with water and silver oxide, a substance is formed which has strongly basic properties. The reaction takes place according to the equation

$$C_6H_5IO + C_6H_5IO_2 + AgOH = (C_6H_5)_2I.OH + AgIO_3.$$

The compound is called *diphenyliodonium hydroxide*—a name which indicates its relation to ammonium, sulphonium, and phosphonium compounds. Diphenyliodonium hydroxide, like other strong bases, forms well-characterized salts with acids, which resemble in solubility the analogous salts of thallium. The compound is of special interest as in it iodine, which under other circumstances is an acid-forming element, plays the part of a base-forming element.

495. Chlorotoluenes, $CH_3.C_6H_4Cl$.—*p*-Chlorotoluene and *o*-chlorotoluene are formed from toluene by the action of chlorine in the presence of a carrier. The ortho compound boils at 159.4° and the para compound at 162.5°. As the difference between the boiling points of the two compounds is so small, it is impossible to separate them by fractional distillation. As a consequence, they are made from the corresponding nitrotoluenes by reactions similar to those indicated in the case of *m*-dibromobenzene.

496. Benzyl chloride, $C_6H_5.CH_2Cl$, is formed when chlorine is passed into boiling toluene or into the cold hydrocarbon exposed to direct sunlight. It is a liquid which possesses a

pungent odor, and boils at 179.4°. The compound enters into the reactions which are characteristic of aliphatic halogen derivatives. When boiled with dilute nitric acid it is oxidized to benzoic acid. By the further action of chlorine, toluene is converted into *benzal chloride*, $C_6H_5.CHCl_2$ (b.p. 214°), and *benzotrichloride*, $C_6H_5.CCl_3$ (b.p. 220.7°). Benzal chloride is prepared commercially in the manufacture of benzaldehyde, $C_6H_3.CHO$; and benzotrichloride in the manufacture of benzoic acid, $C_6H_5.COOH$.

Benzyl chloride causes a copious flow of tears. A compound of analogous structure but derived from xylene, $CH_3C_6H_4CH_2Br$, was used as a lachrymatory gas during the World War. The most efficient gas of this type was bromobenzyl cyanide, C_6H_5-$CHBrCN$. Air containing 0.0003 milligram of the latter per liter produces a flow of tears.

497. Diphenyldichloromethane, $(C_6H_5)_2CCl_2$, can be formed by the replacement of the oxygen atom in benzophenone, $(CH_5)_2CO$, by chlorine. This is effected by heating the ketone with phosphorus pentachloride:

$$(C_6H_5)_2CO + PCl_5 = (C_6H_5)_2CCl_2 + POCl_3$$

The compound can be prepared by other methods, two of which illustrate general reactions. When chlorine is passed into diphenylmethane, which is gently heated, the hydrogen atoms joined to the methane carbon atom are replaced, one after the other, by the halogen. In this way diphenylchloromethane, $(C_6H_5)_2CHCl$, and diphenyldichloromethane, $(C_6H_5)_2CCl_2$, may be prepared conveniently. The latter compound may also be prepared by the Friedel and Crafts reaction from benzene and carbon tetrachloride, in the presence of aluminium chloride. If the reaction takes place in the cold and an excess of carbon tetrachloride is used, but two halogen atoms of the latter are replaced by phenyl. In the presence of an excess of benzene, triphenylchloromethane, $(C_6H_5)_3CCl$, is formed almost exclusively. Halogen derivatives of diphenyldichloromethane are readily prepared by condensing halogen derivatives of benzene with carbon tetrachloride. When chlorobenzene is used, a mixture of the *p,p'*-dichloro and *o,p'*-dichloro derivatives is obtained.

498. Triphenylchloromethane, $(C_6H_5)_3CCl$ (m.p. 112°), which is also called triphenylmethyl chloride, is a compound of importance on account of the fact that it yields a remarkable hydrocarbon, triphenylmethyl (**451**), when treated with zinc. The substance itself possesses unusual properties. It is best prepared by treating benzene with carbon tetrachloride in the presence of aluminium chloride.

The halogen atom in triphenylchloromethane is very reactive. It is replaced by hydroxyl when the latter is allowed to stand with water at room temperature:

$$(C_6H_5)_3C.Cl + HOH \rightleftharpoons (C_6H_5)_3C.OH + HCl$$

The reaction is a reversible one, the equilibrium attained being determined by the amount of water present. When triphenylcarbinol is treated with concentrated hydrochloric acid, triphenylchloromethane is formed, the reaction being the reverse of that just given.

Triphenylchloromethane shows many of the properties of certain inorganic salts. It enters into reactions of double decomposition. The halogen which it contains is precipitated as silver chloride, when a solution of triphenylchloromethane is treated with silver nitrate. It reacts with concentrated sulphuric acid in a manner which is analogous to that in which sodium chloride reacts with the acid:

$$(C_6H_5)_3CCl + H_2SO_4 = (C_6H_5)_3CSO_4H + HCl$$

Triphenylchloromethane forms double salts with certain inorganic halides. The compound with aluminium chloride, which is an example, has the formula $(C_6H_5)_3CCl.AlCl_3$. A solution of triphenylchloromethane in liquid sulphur dioxide conducts an electric current; it appears, therefore, to be dissociated into ions in solution. Triphenylbromomethane is more highly ionized than the analogous chlorine compound. All these facts indicate that triphenylchloromethane resembles in many respects an inorganic salt, and that carbon may be considered a base-forming element. A number of compounds related to triphenylcarbinol and triphenylmethyl chloride have been investigated. In order to indicate their relation to bases and salts they have been called *carbonium* compounds.

Problems

1. (*a*) Summarize the factors that influence substitution in the side chain and in the ring in aromatic compounds. Illustrate by indicating how the following may be prepared: (*b*) $C_6H_5CHCl_2$; (*c*) *p*-$ClC_6H_4CH_2Br$; (*d*) *o*-$BrC_6H_4CHCl_2$; (*e*) *m*-$ClC_6H_4CCl_3$; (*f*) *p*-$ClC_6H_4CCl_3$.

2. By what chemical tests could you distinguish between the following: (*a*) *p*-$ClC_6H_4CH_2Br$ and *p*-$BrC_6H_4CH_2Cl$; (*b*) $(C_6H_5)_3CCl$ and $(ClC_6H_4)_3C$-H; (*c*) $CH_3OC_6H_4Cl$ and $ClCH_2OC_6H_5$; (*d*) $C_6H_5CH_2Cl$ and $C_6H_5CCl_3$; (*e*) $ClC_6H_4COOC_6H_5$ and $C_6H_5COOC_6H_4Cl$; (*f*) $ClC_6H_4CONHC_6H_5$ and C_6H_5-$CONHC_6H_4Cl$; (*g*) $ClC_6H_4CH_2Cl$ and $C_6H_5CHCl_2$.?

3. Write the formulas of the compounds that would be formed when the following are oxidized: (*a*) *p*-$BrC_6H_5CHCl_2$; (*b*) *p*-$CH_3C_6H_4CH_2Cl$; (*c*) *o*-$C_2H_5C_6H_4CH_2CHCl.CH_3$; (*d*) *p*-$C_6H_5C_6H_4Cl$; (*e*) $(C_6H_5)_2CHCl$; (*f*) $C_6H_5CH_2CH_2C_6H_5$.

4. Write the graphic formulas of the compounds you would expect to be formed by the introduction of a single bromine atom into the ring of the compounds listed below. If two monobromo derivatives are expected, give two formulas and state a reason for your opinion in each case. (*a*) *p*-$BrC_6H_4CH_3$; (*b*) $C_6H_5NO_2$; (*c*) *m*-$C_6H_4(NO_2)_2$; (*d*) *p*-$C_6H_4(NO_2)_2$; (*e*) *o*-$C_6H_4(NO_2)_2$; (*f*) *o*-$ClC_6H_4CH_3$; (*g*) *m*-$ClC_6H_4CH_3$; (*h*) *o*-$ClC_6H_4NO_2$; (*i*) *m*-$ClC_6H_4NO_2$; (*j*) *p*-$ClC_6H_4NO_2$.

5. From the following data identify the compound described: The compound is aromatic; boils at 159.4°; contains chlorine, which is not removed by boiling with alcoholic potassium hydroxide. When oxidized, an acid is formed which contains chlorine and melts at 140.7°.

6. A compound contained 52.50 per cent C, 43.75 per cent Cl, and 3.75 per cent H, and its molecular weight was 160. It reacted with an alcoholic solution of potassium hydroxide and yielded on oxidation an acid which contained chlorine. Write a possible formula for the original compound.

CHAPTER XXI

AROMATIC AMINES AND OTHER REDUCTION PRODUCTS OF NITRO COMPOUNDS

499. A great variety of amines containing aromatic radicals is possible, and many are known. These may be divided into two classes: those in which the nitrogen atom present is in combination with a carbon atom in the ring, the so-called arylamines, and those in which it is linked to a carbon atom in the side chain. Benzylamine, $C_6H_5CH_2NH_2$, a member of the second class, may be considered as derived from methylamine by the replacement of one hydrogen atom of the methyl group by phenyl. It resembles methylamine closely in chemical properties and can be prepared by a method analogous to that used in the case of the aliphatic amines, namely, the treatment of benzyl chloride with ammonia. While the aromatic amines which contain an amino group in direct combination with a carbon atom of the nucleus show many of the properties of aliphatic amines, they are sharply differentiated from the latter in certain respects. It has been pointed out that compounds which contain atoms or groups in combination with aryl radicals do not possess all the chemical properties of analogous compounds in which these atoms or groups are linked to carbon atoms in an open chain. Chlorobenzene, for example, is much less reactive than ethyl chloride. For this reason aromatic amines are not usually prepared by the action of ammonia on aryl halides.

500. Preparation of Aromatic Amines.—Compounds of this class are commonly prepared by reducing nitro compounds:

$$C_6H_5NO_2 + 6H = C_6H_5NH_2 + 2H_2O$$

The reduction is usually effected in the laboratory by means of tin and hydrochloric acid. Stannous chloride and hydrochloric acid, zinc or iron and acetic acid, and an alcoholic solution of ammonium sulphide are also used. Ammonium sulphide is of

particular value when it is desired to reduce but one nitro group in a compound which contains two or more of these groups. For example, when *m*-dinitrobenzene is warmed with this reagent, *m*-nitroaniline is formed:

$$C_6H_4(NO_2)_2 + 3(NH_4)_2S = C_6H_4(NO_2)(NH_2) + 6NH_3 + 3S + 2H_2O$$

Certain amines are most conveniently prepared by heating hydroxyl compounds at 300° with the compound of zinc chloride and ammonia. The naphthylamines, $C_{10}H_7NH_2$, are prepared in this way industrially from the naphthols, $C_{10}H_7OH$:

$$2C_{10}H_7OH + ZnCl_2.2NH_3 = 2C_{10}H_7NH_2 + ZnCl_2.2H_2O$$

501. Primary Amines.—The primary aromatic monoamines are liquids or solids which crystallize well. They are colorless when pure, but slowly turn brown when exposed to the air. They possess a characteristic odor, and are very difficultly soluble in water.

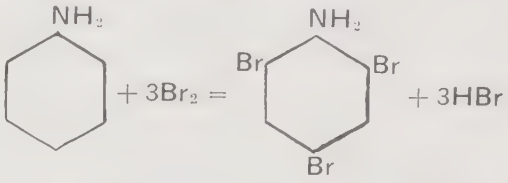
Chemical Reactions. With Acids.—In many of their reactions the aromatic amines resemble the analogous aliphatic compounds. Owing to the presence of the phenyl group the aqueous solutions of the arylamines are much less basic than those of the alkyl amines; an aqueous solution of aniline, $C_6H_5NH_2$, does not affect the color of red litmus. Notwithstanding this, the primary arylamines form with strong acids well-characterized salts, which crystallize from water. The salts are hydrolyzed by water, show an acid reaction, and are decomposed by soluble carbonates. The addition products of the amines with the hydrogen halides form beautifully crystalline double salts, some of which are difficultly soluble in water. A double salt of aniline hydrochloride and platinic chloride has the composition expressed by the formula $PtCl_4.2C_6H_5NH_3Cl$.

With Alkyl Halides.—The primary amines unite with alkyl halides and form salts of secondary and tertiary amines and of the quaternary ammonium bases, the reactions being analogous to those already described in connection with the aliphatic amines. Like the latter they are converted into isocyanides when warmed with potassium hydroxide and an alcoholic solution of chloroform.

With Acyl Chlorides and Anhydrides.—The aromatic amines react also with acyl chlorides and acid anhydrides. Aniline and acetyl chloride give, for example, acetanilide:

$$CH_3COCl + H_2NC_6H_5 = CH_3CO.NHC_6H_5 + HCl$$

With Halogens.—Amines react very readily with the free halogens, the introduction of the halogen atom into the ring being greatly facilitated by the presence of the amino group. When an aqueous solution of aniline is treated with bromine water, symmetrical tribromoaniline is precipitated:



With Nitrous Acid.—Nitrous acid serves to differentiate sharply primary alkylamines from primary arylamines. The salts of the former are converted into alcohols by this reagent. The reaction in the case of methylamine is expressed by the equation

$$CH_3NH_2.HCl + HNO_2 = CH_3OH + N_2 + H_2O + HCl.$$

When a solution of a salt of an arylamine, aniline for example, is treated with nitrous acid, nitrogen is not evolved if the reaction takes place at room temperature. A substance containing nitrogen, which is called a diazonium compound, is formed. The reaction in the case of aniline hydrochloride is expressed by the following equation:

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O$$

The three hydrogen atoms in combination with the nitrogen atom are replaced by a nitrogen atom from the nitrous acid. The diazonium salts, which will be described in detail later, can be isolated. If the reaction between the amine and nitrous acid is brought about in hot water, or the solution of the diazonium salt prepared in the cold is heated, nitrogen is evolved and a phenol, C_6H_5OH, is formed. It is thus seen that nitrous acid serves to replace an amino group in both alkylamines and arylamines by the hydroxyl group. The difference between the two classes consists in the fact that in the case of the arylamines

an intermediate product, the diazonium salt, can be isolated. It will be shown later that diazonium salts can be converted into a great variety of compounds—a fact which leads to the use of primary arylamines in the preparation of many classes of compounds. Benzylamine, $C_6H_5CH_2NH_2$, like the simple alkylamines, cannot be converted into a diazonium compound.

502. Secondary Amines.—The aromatic secondary amines resemble closely the analogous aliphatic compounds. The differences which exist between the two classes can be traced to the presence of aryl groups. Diphenylamine, $(C_6H_5)_2NH$, forms salts with strong solutions of active acids only, and when the salts are treated with water they are completely decomposed into the free amine and free acid. Methylaniline, $C_6H_5(CH_3)NH$, on the other hand, is, as might be expected, more strongly basic than aniline.

Secondary amines like methylaniline can be prepared by the direct addition of an aromatic amine and an alkyl halide:

$$C_6H_5NH_2 + CH_3I = C_6H_5(CH_3)NH.HI$$

As in the case of the aliphatic amines, the reaction does not stop with the formation of the salt of a secondary amine, but tertiary amines and quaternary ammonium bases are also formed.

Amines which contain two aryl radicals are prepared by reactions similar to those indicated by the following equations:

$$C_6H_5NH_2 + C_6H_5NH_2.HCl = (C_6H_5)_2NH.HCl + NH_3$$

$$C_6H_5OH + C_6H_5NH_2 + ZnCl_2 = (C_6H_5)_2NH + ZnCl_2.H_2O$$

Like aliphatic amines, methylaniline and analogous compounds form salts with acids, and addition products with alkyl halides.

They are converted into acyl derivatives by acid anhydrides or acyl chlorides. They yield nitroso compounds with nitrous acid; the derivative prepared from methylaniline has the formula $C_6H_5N(NO)CH_3$.

503. Tertiary Amines.—Amines of this class which contain both alkyl and aryl radicals are formed by the action of alkyl halides on primary or secondary aromatic amines. They are usually prepared commercially, however, by heating to a high

temperature an arylamine with an alcohol and hydrochloric acid:

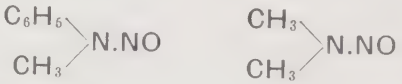
$$C_6H_5NH_2 + 2CH_3OH + HCl = C_6H_5N(CH_3)_2.HCl + 2H_2O$$

Amines which contain three aryl radicals cannot be prepared by these methods. Triphenylamine is formed by heating bromobenzene with a potassium derivative of aniline:

$$2C_6H_5Br + C_6H_5NK_2 = (C_6H_5)_3N + 2KBr$$

Compounds of this type do not form salts with acids.

Tertiary amines which contain both alkyl and aryl radicals resemble in general the aliphatic tertiary amines in their chemical behavior. The two classes are sharply differentiated, however, by their behavior with nitrous acid. While the aliphatic amines are either unaffected or oxidized by this reagent, the aromatic amines are converted into nitroso compounds. The nitroso derivatives of a secondary aromatic amine has a structure analogous to that of the nitroso derivatives of aliphatic amines. The constitution of nitrosomethylaniline and that of nitrosodimethylamine are expressed, respectively, by the following formulas:



In the nitroso derivatives of the tertiary amines, the characteristic group is linked to a carbon atom in the nucleus. The compound formed by the action of nitrous acid on dimethylaniline, for example, has the structure indicated by the formula $NO.C_6H_4.N(CH_3)_2$.

504. Diamines.—Derivatives of aromatic hydrocarbons which contain two or more amino groups are known. They are prepared by reducing nitro compounds which contain two or more nitro groups. The diamines are colorless compounds which rapidly turn brown in the air and are oxidized readily. When they are treated with an aqueous solution of ferric chloride characteristic colors are formed.

505. Aniline, $C_6H_5NH_2$, derives its name from the fact that it was first formed as the result of the distillation of indigo, for which the Spanish name is *anil*. It occurs in small quantities in coal tar and in bone oil.

Aniline is prepared in the laboratory by the reduction of nitrobenzene with tin and hydrochloric acid:

$$C_6H_5NO_2 + 3Sn + 7HCl = C_6H_5NH_2.HCl + 3SnCl_2 + 2H_2O$$

Some stannic chloride is also formed, as stannous chloride in the presence of hydrochloric acid reduces nitrobenzene to aniline, and as a result is oxidized to stannic chloride:

$$C_6H_5NO_2 + 3SnCl_2 + 7HCl = C_6H_5NH_2.HCl + 3SnCl_4 + 2H_2O$$

The product of the reaction is a mixture of the double salts of aniline hydrochloride with stannous chloride and stannic chloride. If the product is allowed to cool when reaction is complete, the double salts are obtained in crystalline condition. Aniline forms many double salts with the halides of the less active metals. The tin salts have the composition expressed by the formulas

$$SnCl_4.2(C_6H_5NH_2.HCl) \quad \text{and} \quad SnCl_2.C_6H_5NH_2HCl.$$

In order to liberate the aniline formed as the result of the reduction of nitrobenzene, the product of the reaction is treated with an excess of sodium hydroxide and distilled with steam. Enough of the alkali must be added to precipitate the tin and to set free the aniline from its hydrochloride.

Aniline is manufactured by two processes. In one, nitrobenzene is reduced by iron and water in the presence of a small amount of hydrochloric acid. In the other, chlorobenzene is heated with water and ammonia at a high temperature and under pressure; cuprous chloride is used as a catalytic agent.

506. *Properties.*—Aniline is a colorless oily liquid, which turns brown on standing unless it is pure. It melts at $-6.2°$, boils at $184.4°$, and has the specific gravity $1.022^{20°}_{4°}$. It is soluble in about 30 parts of water. An aqueous solution of free aniline gives a violet coloration with a solution of bleaching powder, and a blue coloration with a solution of potassium dichromate. A solution of aniline which contains an acid is colored dark green by potassium dichromate.

Aniline is converted into a sulphonic acid when heated with concentrated sulphuric acid, into halogen substitution products by the halogens, and into nitro derivatives by nitric acid. These compounds will be considered in some detail later.

507. Acetanilide, $C_6H_5NH.COCH_3$, which is an important derivative of aniline, is an example of the compounds formed as the result of the replacement of a hydrogen atom in an aromatic amine by acyl radicals. Acetanilide is formed when aniline is treated with acetyl chloride or acetic anhydride:

$$C_6H_5NH_2 + CH_3COCl = C_6H_5NH.COCH_3 + HCl$$

It is usually prepared by boiling for some hours aniline acetate, which is formed by mixing aniline and acetic acid:

$$C_6H_5NH_2.CH_3COOH = C_6H_5NH.COCH_3 + H_2O$$

Acetanilide crystallizes from hot water in white prisms. It melts at 114.2° and boils at 303.8°. It is used in medicine in cases of fever, and in "headache powders" and is called "antifebrin."

Acetanilide is hydrolyzed when heated with an aqueous solution of a base:

$$C_6H_5NH.COCH_3 + KOH = C_6H_5NH_2 + CH_3.COOK$$

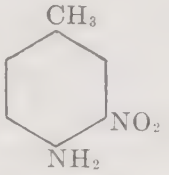
508. The acetyl derivatives of aromatic amines are often used in the preparation of substitution products of the amines. Aniline and its homologues are very reactive substances and, as a consequence, the reactions which they undergo with other compounds cannot always be controlled. Aniline, for example, is largely converted into tribromoaniline by bromine water. It is not possible to prepare conveniently monobromoaniline from the free amine. In order to decrease the activity of the compound, one of its hydrogen atoms is replaced by an acetyl radical. Acetanilide and bromine yield bromoacetanilide, from which bromoaniline is obtained by hydrolysis:

$$C_6H_5NH.COCH_3 + Br_2 = BrC_6H_4NH.COCH_3 + HBr,$$
$$BrC_6H_4NH.COCH_3 + KOH = BrC_6H_4NH_2 + CH_3COOK$$

Acetyl compounds are often used in the preparation of nitro derivatives of amines, and when it is desired to oxidize a side chain in an amine.

509. Toluidines, $CH_3.C_6H_4.NH_2$.—The three isomeric toluidines are obtained by the reduction of the three nitrotoluenes. When toluene is nitrated the product of the reaction consists almost entirely of the para and ortho derivatives. From these *p-toluidine* (m.p. 43.7°, b.p. 200.5°) and *o-toluidine* (b.p. 200.7°) are readily obtained. The two amines may be separated by making use of the difference in solubility of their oxalates.

510. *m-Toluidine.*—As the nitro group does not, under ordinary conditions, enter the ring in a position meta to a methyl radical, it is necessary to prepare *m*-nitrotoluene by an indirect method. This method is of interest, as it is a good example of the procedure adopted by chemists to introduce a substituent into a position which it will not enter normally. When *p*-toluidine is treated with nitric acid the two groups present, methyl and amino, have a directing influence on the nitro group introduced into the compound. Both of these groups tend to send a substituent to the ortho and para positions. As in *p*-toluidine the position para to methyl is occupied by the amino group, the entering group must take its place ortho to either of these groups. The latter exerts a stronger directing influence than methyl, and as a consequence the chief product of the reaction has the structure represented by the formula



The yield of nitro compound is small when *p*-toluidine is nitrated, as amines, in general, undergo deep-seated changes when treated with nitric acid. In order to prevent this, the acetyl derivative of *p*-toluidine is nitrated, and the free amine obtained from the resulting product by saponification.

In this way a nitro group is introduced into the ring in a position meta to the methyl radical. In order to obtain nitrotoluene from the nitrotoluidine formed in this way, the amino group present in the latter must be removed. This is accomplished by converting the amine into a diazo compound (**527**), and boiling the latter with alcohol, when the diazo group is replaced by hydrogen:

$$CH_3C_6H_3(NO_2)N_2Cl + C_2H_5OH = CH_3.C_6H_4.NO_2 + N_2 + HCl + CH_3.CHO$$

m-Toluidine is obtained by reducing *m*-nitrotoluene formed by this roundabout process.

511. As the boiling points of *o*-, *m*-, and *p*-toluidine, are, respectively, 200.7°, 203.3°, and 200.5°, it is impossible to identify these compounds by a determination of their boiling points. The identification can be effected, however, by a determination of the melting points of their acetyl derivatives, which are formed when the amines are treated with acetic anhydride. The acetyl derivatives of *o*-, *m*-, and *p*-toluidine melt at 110°, 65.5°, and 153°, respectively. In order to identify a substance it is necessary to determine the physical properties of the substance and of at least

one of its derivatives. The method used in the identification of the toluidines is an excellent example of this principle.

512. Benzylamine, $C_6H_5CH_2NH_2$, is an example of an amine with the amino group in the side chain. It can be obtained by the methods used to prepare methylamine. As in the case of the purely aliphatic amine, secondary and tertiary amines are formed. In order to prevent this, benzyl chloride may be treated with acetamide instead of with ammonia:

$$C_6H_5CH_2Cl + NH_2.COCH_3 = C_6H_5CH_2NH.COCH_3 + HCl$$

From the acetyl derivative of benzylamine formed in this way, the free amine is obtained by hydrolysis.

Benzylamine is a liquid of ammoniacal odor, which boils at 184°, has the specific gravity $0.980^{\frac{20°}{4°}}$, and absorbs carbon dioxide from the air. It shows the properties characteristic of aliphatic amines and cannot be converted into a diazo compound.

513. Naphthylamines, $C_{10}H_7NH_2$.—α-Naphthylamine is made by reducing α-nitronaphthalene or heating α-naphthol, $C_{10}H_7OH$, with the ammonia compound of calcium chloride or zinc chloride:

$$C_{10}H_7.OH + NH_3 = C_{10}H_7.NH_2 + H_2O$$

It is also manufactured by heating α-naphthol with an aqueous solution of ammonia and ammonium sulphite at 120° to 150° in an autoclave. It possesses a disagreeable fæces-like odor, sublimes readily, and turns brown in the air. It crystallizes in colorless needles or prisms, melts at 50°, and boils at 301°. Solutions of its salts give a blue precipitate with ferric chloride and other oxidizing agents.

β-Naphthylamine is prepared from β-naphthol, by the method employed in the case of its isomer. It crystallizes in glancing mother-of-pearl plates, melts at 110.2°, boils at 306.1°, and has no odor. It is not colored by oxidizing agents.

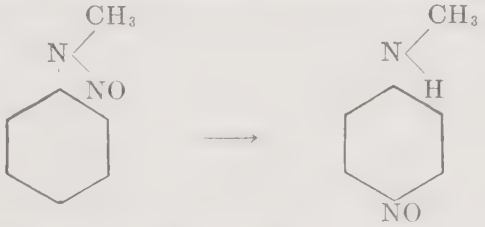
The naphthylamines are used extensively in the manufacture of dyes.

514. Methylaniline, $C_6H_5NHCH_3$, is an example of a secondary amine which contains an aryl and an alkyl radical. It is prepared commercially for use in the manufacture of dyes by heating aniline hydrochloride with methyl alcohol under pres-

sure. Methylaniline is an oil, lighter than water, which boils at 195.7°.

When a solution of methylaniline in an acid is treated with nitrous acid, *N-nitrosomethylaniline*, $C_6H_5.N(NO)CH_3$, is formed. The compound is a yellow oil of aromatic odor, which cannot be distilled without decomposition. It can be distilled with steam unchanged, however. On careful reduction it is converted into a derivative of hydrazine, $C_6H_5N(CH_3).NH_2$, and when treated with tin and hydrochloric acid, the nitroso group is eliminated and methylaniline is formed.

515. *N*-nitrosomethylaniline and similar compounds undergo a molecular rearrangement when heated with a solution of hydrogen chloride in alcohol; the nitroso group enters into combination with the carbon atom para to the nitrogen atom. In this way *N*-nitrosomethylaniline, which is also called methylaniline-nitrosamine, is converted into *p*-nitrosomethylaniline:



The last named compound unites with acids and forms salts, whereas the compound which contains the nitroso group in combination with nitrogen lacks basic properties.

A similar rearrangement takes place when the hydrochloride of methylaniline is heated to a relatively high temperature; the hydrogen atom, in the position para to nitrogen, and the methyl group change places, and the hydrochloride of paratoluidine is formed.

516. Diphenylamine, $(C_6H_5)_2NH$, is an example of a purely aromatic amine. The method used in its preparation has been discussed under secondary amines (**502**). Diphenylamine has an agreeable odor, melts at 53°, and boils at 302°. It serves as a reagent for the detection of traces of nitric acid and other oxidizing substances. When a solution of the amine in concentrated sulphuric acid is treated with a trace of nitric acid, a deep blue color is developed.

517. Dimethylaniline, $C_6H_5.N(CH_3)_2$, is an oil, which solidifies when cooled by a freezing mixture, and boils at 193.5°. It is manufactured by heating aniline hydrochloride with methyl

alcohol under pressure. The hydrogen atom of the amine which is in the position para to the $N(CH_3)_2$ group is very reactive. As a consequence, dimethylaniline forms condensation products when treated with a variety of compounds. For example, when the amine and benzoic aldehyde, $C_6H_5.CHO$, are heated in the presence of zinc chloride, condensation takes place:

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

Reactions of this type will be discussed later in the consideration of dyes.

When a solution of dimethylaniline in an acid is treated with nitrous acid, a salt of *p-nitrosodimethylaniline* is formed:

$$C_6H_5.N(CH_3)_2HCl + HNO_2 = NO.C_6H_4.N(CH_3)_2.HCl + H_2O.$$

The salt so formed crystallizes in yellow needles. The free amine, which is liberated from its salts by bases, crystallizes in green plates, which melt at 85°. When *p*-nitrosodimethylaniline is boiled with an alkali, dimethylamine and a salt of nitrosophenol are formed:

$$NO.C_6H_4.N(CH_3)_2 + KOH = NO.C_6H_4.OK + (CH_3)_2NH$$

The reaction furnishes the most convenient way of preparing dimethylamine.

518. Identification of Aromatic Amines.—Most aromatic amines are soluble in hydrochloric acid and are precipitated from the solution of their salts so formed by bases. Aqueous solutions of the amines, even when very dilute, yield precipitates of bromine substitution products when treated with bromine water. The reaction is not characteristic, however, as phenols act in a similar way.

The class to which an amine belongs can be determined by treating it with acetyl chloride or acetic anhydride. The reactions which take place with these substances are analogous to those described under the aliphatic amines. Benzenesulphonyl chloride is of particular value in distinguishing primary, secondary, and tertiary amines from one another. The reactions have already been described (**482**).

The behavior of aromatic amines with nitrous acid is characteristic. The reagent serves to distinguish not only primary, secondary, and tertiary amines from one another, but aromatic

amines from aliphatic amines in the case of primary and tertiary compounds.

When a compound has been shown to be an amine, and the class to which it belongs has been ascertained, its identification is completed by the determination of the melting point or boiling point of a compound prepared from it. Acetyl derivatives are frequently prepared in identifying amines, as many of them melt sharply and crystallize well from water.

Intermediate Reduction Products of Nitrobenzene

519. The substance formed when nitrobenzene is reduced is determined by the nature of the reducing agent used. When, for example, hydrogen generated by the action of a metal on an acid is the reducing agent, aniline is formed; when the reduction is effected by treating nitrobenzene with zinc dust and water, the reaction product is phenylhydroxylamine, $C_6H_5.NHOH$.

The study of the reduction of organic compounds has led to the important conclusion that the various reducing agents differ markedly in the effect they produce. The activity of a reducing agent is determined by the energy relations involved in the changes which take place during reduction. When "nascent" hydrogen is the reducing agent, its activity is determined by what may be called the pressure or tension under which it is liberated. This pressure can be varied by selecting various combinations of substances which yield hydrogen, or by generating the gas by means of electricity.

520. *Electrolytic Reduction.*—The electromotive force required to liberate hydrogen from a solution of an acid changes as the metal used for the cathode is changed. Since the measure of electrical energy is the product of volts $\times$ coulombs, a larger amount of energy is available when hydrogen is set free by a current at a high potential than when the metal of the cathode permits the liberation of the reducing agent at a low voltage. The difference between the minimum voltage required to liberate hydrogen—that of a reversible hydrogen electrode—and the actual voltage required in the case of any cathode is called the *overvoltage* of the material of which the cathode is made. The metals differ in the overvoltage required to liberate hydrogen when they are used as cathodes, and, accordingly, produce different effects when they are used in connection with electrolytic reduction. The overvoltage of smooth platinum is about 0.09 of a volt, while that of lead is about 0.64 of a volt. The *concentration* of the hydrogen is also an important factor in the electrolysis of organic compounds; this can be varied by

changing the so-called current density, *i.e.*, the relation between the area of the electrode and the amount of current passing in a given time. The current density is expressed in amperes per square decimeter. When a high concentration of discharged ions is required a high current density is used. For example, in the electrolysis of an aqueous solution of acetic acid, the acetate ion, CH_3COO^-, is liberated at the anode. If the current density at the anode is low, the concentration of the discharged ions is low and they react with water and form acetic acid and oxygen. If the current density is high and the concentration of the discharged ions likewise high, the latter react with each other and ethane and carbon dioxide are formed: $2CH_3COO^- = C_2H_6 + 2CO_2$. The application of the electric current in the preparation of organic compounds has been studied in some detail and new processes based on such methods are coming into technical use.

521. An examination of the methods used to prepare the various reduction products of nitrobenzene brings out clearly the fact that reducing agents differ among themselves in activity. The study of the action of oxidizing agents on organic compounds has led to a similar conclusion in the case of these substances.

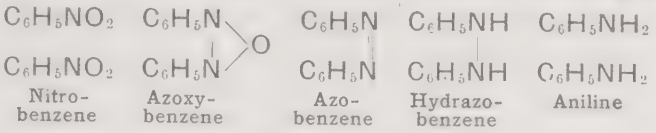
The primary reduction products of nitrobenzene are represented by the following formulas:

$$C_6H_5NO_2 \rightleftharpoons C_6H_5NO \overset{H}{\underset{O}{\rightleftharpoons}} C_6H_5NHOH \rightleftharpoons C_6H_5NH_2$$

By reduction, it is possible to pass from nitrobenzene to aniline through the intermediate compounds nitrosobenzene and phenylhydroxylamine, and by oxidation in the reverse direction. It has been shown that nitrosobenzene and phenylhydroxylamine are formed in the electro-reduction of nitrobenzene, but it is impossible, at present, to effect some of the transformations indicated above in such a way that the reactions can be used as preparative methods. Some, however, can be used for this purpose. Phenylhydroxylamine, for example, is oxidized in the cold by potassium dichromate and sulphuric acid to nitrosobenzene, and is converted by reducing agents into aniline. In certain cases it is possible, by selecting the proper reagent, to effect the change indicated by two of the steps noted above. Phenylhydroxylamine is best prepared by treating with zinc dust a solution of nitrobenzene in dilute alcohol which contains a small amount of calcium chloride.

The effect of reducing agents on nitrobenzene is clearly shown by a study of the series of what may be called secondary reduc-

tion products, which contain two benzene rings; the composition of these compounds is represented by the following formulas:



522. Azoxybenzene, $C_6H_5N{-\!-}NC_6H_5$ (O), is obtained by boiling nitrobenzene with an alcoholic solution of potassium hydroxide. Alcohol in the presence of an alkali is frequently used as a mild reducing agent. Azoxybenzene is formed when an alcoholic solution of aniline is treated with potassium permanganate. It is a light-yellow, crystalline substance, which melts at 36°. Active reducing agents convert it into aniline.

523. Azobenzene, $C_6H_5N{=}NC_6H_5$, is prepared by reducing nitrobenzene with a solution of sodium stannite, which is made by treating stannous chloride with an excess of sodium hydroxide. It will be recalled that stannous chloride in acid solution reduces nitrobenzene to aniline. The difference between the activity of a reducing agent in an acid solution and the activity of the same reagent in alkaline solution, which is seen here, has been noted in other cases. Azobenzene is formed when azoxybenzene is distilled with iron filings. It forms orange-red crystals, melts at 67°, boils at 297.4°, and is converted into aniline by active reducing agents.

524. Hydrazobenzene, $C_6H_5NH.NHC_6H_5$, is formed by the reduction of nitrobenzene by zinc dust in alkaline solution. The presence of the alkali is necessary, as in neutral solution phenylhydroxylamine is formed, and in acid solution aniline is the reduction product. Hydrazobenzene forms colorless crystals which melt at 131°. It is readily oxidized to azobenzene, the change being effected by ferric chloride, and slowly by the oxygen of the air.

525. Benzidine.—Under the influence of strong acids hydrazobenzene undergoes a molecular rearrangement, as the result of which *benzidine*, which is a diaminobiphenyl, is formed:

Benzidine is formed directly by reducing azobenzene in acid solution. The structure of the amine has been shown to be that indicated, by converting it into diphenyl. The amino groups may be replaced by hydrogen by the method outlined in the case of nitrotoluidine (**509**). Benzidine crystallizes in colorless, silky plates, which melt at 128.7°. It is characterized by its solubility in hot water, and the sparing solubility of its sulphate. It is used in large quantities in the manufacture of certain dyes.

Problems

1. Summarize in equations two methods that can be used to distinguish primary, secondary, and tertiary amines.

2. Write equations for reactions by which the following may be prepared: (*a*) $C_6H_5NCH_3.C_2H_5$ from $C_6H_5NH_2$; (*b*) p-$NO_2C_6H_4NH_2$ from C_6H_6; (*c*) m-$NO_2C_6H_4NH_2$ from C_6H_6; (*d*) o-$ClC_6H_4NH_2$ from benzene; (*e*) m-$ClC_6H_4NH_2$ from C_6H_6; (*f*) p-$NO_2C_6H_4CH_2NH_2$ from $C_6H_5CH_3$.

3. By what chemical reactions could the following be distinguished: (*a*) $ClC_6H_4NH_3Br$ and $BrC_6H_4NH_3Cl$; (*b*) $ClC_6H_4NHCOCH_3$ and $C_6H_5NHCOCH_2Cl$; (*c*) $C_6H_5NH_2.H_2SO_4$ and p-$NH_2C_6H_4SO_3H$; (*d*) $C_6H_5N(CH_3)_3Cl$ and p-$ClC_6H_4NH_2$?

4. If you found as the result of a qualitative analysis that a substance contains nitrogen what tests would you apply to determine whether or not it is (*a*) a primary amine, (*b*) a nitro compound, (*c*) an amide, (*d*) a salt of an amine?

CHAPTER XXII

DIAZO COMPOUNDS

526. The compounds formed by the action of nitrous acid on the salts of primary aromatic amines are of great theoretical interest and practical importance. The compound obtained from aniline hydrochloride has the composition represented by the formula $C_6H_5N_2Cl$. As it contains two nitrogen atoms, it was originally called a diazo compound, the second syllable of the name being derived from *azote*, the French word for nitrogen. Since their discovery in 1860 by Griess the diazo compounds have been much studied. They are very reactive and yield various classes of compounds, among which are important dyes, when they enter into reaction with other substances.

Diazo compounds are formed when an ice-cold acidified aqueous solution of a salt of a primary aromatic amine is treated with a solution of sodium nitrite. The reaction which takes place in the case of aniline hydrochloride is represented by the equation

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O.$$

The diazo compound prepared in this way from aniline hydrochloride cannot be isolated, as it is soluble in water and decomposes when an attempt is made to obtain it by evaporation of the solution. In the use of diazo compounds to prepare other substances it is in general unnecessary to isolate them, and the reactions are accordingly carried out in aqueous solution. When it is desired to obtain the diazo compounds in pure condition, they are prepared in a different way. In this method the salt of the amine is suspended in alcohol and treated either with amyl nitrite or with the oxides of nitrogen formed by heating arsenious acid with nitric acid. When reaction is complete, ether is added to precipitate the salt of the diazo compound, which is obtained in crystalline condition.

The salts of the diazo compounds are soluble in water, and resemble inorganic salts in certain respects. Their solutions

conduct an electric current and enter into the ordinary reactions of double decomposition. The chlorides form double salts such as those with platinum, $PtCl_4.2C_6H_5N_2Cl$, and with gold, $AuCl_3.C_6H_5N_2Cl$. The determinations of the conductivity of the salts lead to the conclusion that they are ionized to about the same extent as ammonium salts. When a solution of the diazo compound prepared from aniline hydrochloride is treated with silver oxide, silver chloride is precipitated and an alkaline solution is obtained:

$$C_6H_5N_2Cl + AgOH = C_6H_5N_2OH + AgCl$$

The diazo compound formed in this way is a strong base.

All these facts lead to the conclusion that the diazo compounds resemble ammonium compounds in structure. In order to emphasize this conclusion, the word diazo has been replaced by the word *diazonium* in naming the compounds which have been described above. The compound of the formula $C_6H_5N_2Cl$ is, thus, benzenediazonium chloride; its structure is represented by the formula

$$C_6H_5.N.Cl \quad (\equiv N) \qquad \text{or} \qquad \left[C_6H_5.N \equiv N \right] Cl$$

It will be shown later that compounds of the structure $C_6H_5.N=N.X$ exist; these are called diazo compounds, and do not possess the salt-like properties of the diazonium compounds.

527. Reactions of Diazonium Salts.—The diazonium salts enter into reaction with various classes of compounds, and as a result are much used in the synthesis of other substances. The reactions are of two types—those in which the nitrogen is eliminated and those in which it is not eliminated. The reactions of the first type result in the replacement of the diazonium group by other groups. The more important of these are as follows:

1. *Replacement of the Diazonium Group by Hydroxyl.*—This can be effected by heating the diazonium salt with water:

$$C_6H_5N_2Cl + HOH = C_6H_5OH + N_2 + HCl$$

In this way aniline, $C_6H_5NH_2$, can be converted into phenol, C_6H_5OH. As aromatic amines are prepared from nitro compounds, which are formed by the action of nitric acid on hydrocarbons, the reaction furnishes what is at times the most

convenient method of introducing a hydroxyl group into a hydrocarbon.

2. *Replacement of the Diazonium Group by Alkoxyl Groups.*—Diazonium salts react with the organic substitution products of water, such as alcohols and phenols:

$$C_6H_5N_2Cl + HOCH_3 = C_6H_5OCH_3 + N_2 + HCl$$

When a diazonium salt is boiled with an alcohol, an ether which contains an aryl and an alkyl group is formed.

3. *Replacement of the Diazonium Group by Hydrogen.*—In certain cases diazonium salts are converted into hydrocarbons when heated with alcohols:

$$C_6H_5N_2Cl + C_2H_5OH = C_6H_6 + N_2 + CH_3CHO + HCl$$

The alcohol loses hydrogen, which takes the place of the diazonium group, and is thereby converted into an aldehyde. Whether hydrogen or an alkoxyl group enters into combination with the aryl radical is determined by the nature of the diazonium compound and alcohol, and by the conditions under which decomposition takes place, such as the temperature and the pressure.

4. *Replacement of the Diazonium Group by Halogens.*—This reaction is accomplished by heating an aqueous solution of the diazonium salt with hydrochloric, hydrobromic, or hydriodic acid. The yield of the chloride and bromide formed is greatly increased by effecting the decomposition in the presence of finely divided copper (*Gattermann reaction*), or by pouring the solution of the diazonium salt into a warm solution of cuprous chloride or cuprous bromide (*Sandmeyer's reaction*). Replacement of the diazonium group by iodine takes place readily when a solution of the diazonium salt which contains free acid is warmed with a solution of potassium iodide. In the preparation of bromides and iodides the sulphate of the amine is commonly used:

$$C_6H_5N_2.SO_4H + HI = C_6H_5I + N_2 + H_2SO_4$$

As iodine substitution products are not formed readily by the action of the free halogen on hydrocarbons, iodo derivatives are usually prepared from amines by means of the diazo reaction.

5. *Replacement of the Diazonium Group by the CN Group.*—This is readily effected by adding the solution of the diazonium

salt to a warm solution of cuprous cyanide in potassium cyanide:

$$C_6H_5N_2Cl + CuCN = C_6H_5CN + N_2 + CuCl$$

The reaction is much used, as it furnishes a convenient method of preparing nitriles, which are converted by hydrolysis into acids.

6. *Replacement of the Diazonium Group by Hydrocarbon Residues.*—When dry diazonium salts are warmed with hydrocarbons in the presence of aluminium chloride, the N_2 group is replaced by aryl radicals:

$$C_6H_5N_2Cl + C_6H_6 = C_6H_5.C_6H_5 + N_2 + HCl$$

When an aqueous solution of a diazonium salt is heated with an excess of a phenol, a derivative of biphenyl is obtained:

$$C_6H_5N_2Cl + C_6H_5OH = C_6H_5.C_6H_4OH + N_2 + HCl$$

p-Hydroxybiphenyl is conveniently prepared in this way; a small amount of the ortho compound is formed at the same time.

7. *Replacement of the Diazonium Group by Sulphur and Nitro and Other Groups.*—This has been effected in a number of cases, but the reactions have not been generally applied in synthetic work.

The reactions of the second type into which diazonium salts enter consist of condensations with other compounds as the result of which substances are formed which contain the diazo or the azo group,—N=N—.

528. Diazoamino Compounds.—When a diazonium salt is treated with an aromatic primary or secondary amine in neutral solution, or in the presence of a weak acid like acetic acid, condensation takes place and a diazoamino compound is formed:

$$C_6H_5N_2Cl + H.NH.C_6H_5 = C_6H_5N_2.NH.C_6H_5 + HCl$$

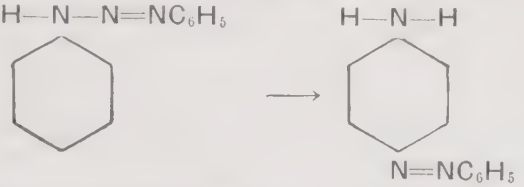
Diazoaminobenzene crystallizes from benzene in flat, yellow prisms, which melt at 96°.

The diazoamino compounds crystallize well and are comparatively stable. They are very weak bases, and form, in certain cases, double salts with chloroplatinic acid. In acid

solution they are converted by nitrous acid into diazonium salts:

$$C_6H_5N_2NHC_6H_5 + HNO_2 + 2HCl = 2C_6H_5N_2Cl + 2H_2O$$

Diazoamino compounds undergo a rearrangement when warmed with an amine and a salt of an amine. When diazoaminobenzene, for example, is heated at 40° with aniline and aniline hydrochloride, *p*-aminoazobenzene is formed:



In the rearrangement the $C_6H_5N_2$ group exchanges places with the hydrogen atom para to the nitrogen atom joined to the ring. A similar rearrangement has been noted in the case of *N*-nitrosomethylaniline (**515**) and other derivatives of amines which contain a negative group in combination with nitrogen. It will be shown later that the benzenediazonium group $C_6H_5N{=}$ is a base-forming group, whereas the isomeric benzenediazo group $C_6H_5N{=}N{-}$, which is present in diazoaminobenzene, is acid-forming.

529. Aminoazo compounds are formed as the result of the rearrangement of diazoamino compounds, or by the condensation of diazonium salts with tertiary aromatic amines. Benzenediazonium chloride and dimethylaniline condense and form *p-dimethylaminoazobenzene:*

$$C_6H_5N_2Cl + HC_6H_4N(CH_3)_2 = C_6H_5N:N.C_6H_4N(CH_3)_2 + HCl$$

They can also be prepared by the reduction of the compounds formed by the nitration of azo compounds:

$$C_6H_5N:NC_6H_4NO_2 + 6H = C_6H_5N:NC_6H_4NH_2 + 2H_2O$$

The aminoazo compounds are weak bases. Those which contain the amino group are converted into diazo compounds by nitrous acid. Reducing agents convert them into amines. Thus, *p*-dimethylaminoazobenzene yields aniline and dimethyl-*p*-phenylenediamine on reduction:

$$C_6H_5N:NC_6H_4N(CH_3)_2 + 4H = C_6H_5NH_2 + H_2NC_6H_4N(CH_3)_2$$

p-Aminoazobenzene crystallizes in yellow leaflets, melts at 126° and boils without decomposition above 360°. Its stability is noteworthy. It forms a hydrochloride which crystallizes in violet needles. It is converted by reducing agents into aniline and *p*-phenylenediamine. Aminoazobenzene and its derivatives are used as dyes.

530. Hydroxyazo Compounds.—Diazonium salts react with phenols in the presence of alkalies and form hydroxyazo compounds:

$$C_6H_5.N_2Cl + C_6H_5OH = C_6H_5.N:N.C_6H_4OH + HCl$$

The azo group enters the position para to hydroxyl; and if this is occupied an ortho compound is formed. The directing influence of the hydroxyl group is, thus, the same as toward atoms or simple groups. *p*-Hydroxyazobenzene crystallizes in orange-colored prisms which melt at 152°. Hydroxyazo compounds are valuable dyes.

531. Hydrazines.—The diazonium salts are converted into amines by active reduction; if, however, the process is regulated, hydrazines are formed. When one mole of benzenediazonium chloride is treated with the amount of stannous chloride and hydrochloric acid equivalent in reducing power to 4 grams of hydrogen, phenylhydrazine hydrochloride is formed:

$$C_6H_5N_2Cl + 4H = C_6H_5NH.NH_2.HCl$$

The hydrazines possess basic properties and yield crystalline salts with acids. They are decomposed into amines and ammonia by energetic reducing agents and are readily affected by oxidizing agents. Phenylhydrazine sulphate, for example, is converted into benzenediazonium sulphate by mercuric oxide, and into water, nitrogen, and benzene by an alkaline solution of a cupric salt. *Phenylhydrazine* is a colorless oily liquid, which turns brown in the air, melts at 19.6°, and boils with slight decomposition at 243.5°. It is sparingly soluble in water and is an active poison. Phenylhydrazine has been of great value in the investigation of carbohydrates. It is a valuable reagent in the study of aldehydes and ketones.

532. Structure of Diazo Compounds.—The reasons for the structure assigned to the diazo compounds which are formed in acid solution have been given (**526**). These considerations

lead to the conclusion that benzenediazonium chloride has the structure represented by the formula $C_6H_5—N—Cl$ (with the N—Cl group written as ‖N). According to this conception, the diazonium salt is formed as the result of the replacement of the three hydrogen atoms in the salt of the amine by the trivalent nitrogen atom of nitrous acid.

Diazoates.—When a solution of benzenediazonium chloride is shaken with silver oxide, silver chloride is precipitated and a strongly alkaline solution is formed. This solution reacts with potassium hydroxide, and a salt is formed called potassium benzenediazoate. The reaction has no analogy among inorganic compounds, as bases do not react with strong bases to form salts. For this reason it is assumed that benzenediazonium hydroxide, which is a strong base, undergoes molecular rearrangement in the presence of an alkali into an isomeric form, which possesses the properties of an acid. The diazonium hydroxide is a substitution product of ammonium hydroxide, and the isomeric form is a substitution product of nitrous acid. The relation between the two forms is shown by the following formulas:

$H—N(=H_3)—OH$ $\quad C_6H_5—N(=N)—OH$ $\quad$ and $\quad O(=N—OH)\ldots N(=N—OH)—C_6H_5$

This hypothesis is in accord with the fact that benzenediazonium hydroxide is a base and benzenediazo hydroxide is an acid, and that the salts of the latter exist in two stereochemical modifications—the *syn-* and *anti*-diazotates.

533. Aliphatic Diazo Compounds.—It has been stated that primary aliphatic amines do not yield diazonium compounds when treated with nitrous acid. It is of interest to note, however, in connection with the aromatic diazo compounds, that certain derivatives of the aliphatic amines yield compounds when treated with nitrous acid which resemble somewhat in their reactions the diazonium compounds. When the ethyl ester of aminoacetic acid is treated with nitrous acid a yellow oil is obtained, which explodes when heated. The reaction takes place according to the equation

$$NH_2CH_2COOC_2H_5 + HNO_2 = N{:}N{:}CHCOOC_2H_5 + 2H_2O.$$

Diazoacetic ester is converted by water into ethyl glycolate, $HOCH_2COOC_2H_5$, into ethyl chloroacetate by hydrochloric acid, and into ethyl diiodoacetate by iodine; in all cases nitrogen is set free.

534. Diazomethane, $CH_2{:}N{\vdots}N$, has been prepared by a series of reactions. It is a yellow gas that liquefies at $-23°$ and reacts at room temperature with a variety of compounds. It causes the replacement by the methyl radical of the hydrogen of hydroxyl groups of amines and of aldehydes. Alcohols are converted into ethers, acids into esters, and aldehydes into ketones. An alternate formula for diazomethane has been proposed: $\begin{matrix} N \\ \| \\ N \end{matrix}\!\!>\!CH_2$. The arrangement of atoms in compounds of similar structure, which are called *diazenes*, is not known with certainty.

Problems

1. Show by equations how the following substances may be prepared through the use of diazo compounds: (*a*) p-$CH_3C_6H_4COOH$; (*b*) m-$NO_2C_6H_4OH$; (*c*) o-$ClC_6H_4OCH_3$; (*d*) o-$IC_6H_4CH_3$.

2. Why is *m*-nitrophenol usually made through the use of the diazo reaction and the ortho and para compounds by direct nitration of phenol? (*b*) When is it desirable to prepare compounds containing two kinds of substituents with the aid of the diazo reaction?

CHAPTER XXIII

AROMATIC ALCOHOLS, PHENOLS, AND ETHERS

535. The hydroxyl derivatives of the aromatic hydrocarbons may be sharply divided into two classes according to their chemical properties; those of one class resemble closely the aliphatic alcohols, while those of the other possess weakly acidic properties and form salts with aqueous solutions of alkalies. The difference between the two classes of compounds results from the fact that in the aromatic alcohols, such as benzyl alcohol, C_6H_5-CH_2OH, the hydroxyl group is situated in the side chain, whereas in the other class of derivatives, which are called phenols, the hydroxyl group is linked to a carbon atom of the ring. Benzyl alcohol may be considered as a substitution product of methyl alcohol formed as the result of the replacement of one hydrogen atom by a phenyl radical. We can readily understand, therefore, the close relationship in properties which exists between the two compounds. In the case of phenol, the hydroxyl group is linked to a carbon atom of a benzene ring, and we have already seen that the nature of an aryl radical is such that compounds formed by its union with other groups possess certain characteristic properties.

Aromatic Alcohols

The chemistry of the aromatic alcohols may be well illustrated by a consideration in some detail of a few typical members of the series.

536. Benzyl alcohol, $C_6H_5CH_2OH$, occurs in the balsam of Peru in the free condition, and in combination as the esters of benzoic acid and cinnamic acid. It is also present in small quantity in the volatile oil of cherry laurel. The alcohol is a liquid, which possesses a faint odor, is difficultly soluble in water, and boils at 205.8°.

Benzyl alcohol may be prepared by the methods used in the preparation of aliphatic alcohols. For example, it is formed when benzyl chloride is heated with water:

$$C_6H_5CH_2Cl + HOH = C_6H_5CH_2OH + HCl$$

As in the case of the aliphatic compounds the rate of the reaction is increased by bringing about the substitution of hydroxyl for chlorine in the presence of potassium carbonate or lead hydroxide.

A method often used in the case of aliphatic compounds can be employed with advantage in the preparation of benzyl alcohol. The method consists in the conversion of an alkyl halide into an acetate, and the saponification of the latter:

$$CH_3COONa + ClCH_2C_6H_5 = CH_3COO.CH_2C_6H_5 + NaCl$$
$$CH_3COO.CH_2C_6H_5 + NaOH = CH_3COONa + C_6H_5CH_2OH$$

Benzyl alcohol can also be prepared by reducing benzoic aldehyde with sodium amalgam and water:

$$C_6H_5CHO + 2H = C_6H_5CH_2OH$$

It can be prepared from benzoic aldehyde by the *Cannizzaro reaction.* It will be recalled that alkalies convert aliphatic aldehydes into resins, which are condensation products of the aldehydes. A reaction of a different nature takes place with aromatic aldehydes and with some of the higher aliphatic aldehydes. That with benzoic aldehyde is typical:

$$2C_6H_5CHO + NaOH = C_6H_5COONa + C_6H_5CH_2OH$$

The reaction indicated above takes place when benzoic aldehyde is shaken with an aqueous solution of sodium hydroxide; it furnishes a convenient method of preparing small quantities of benzyl alcohol. It is probable that the reaction consists in the addition of two molecules of the aldehyde to form benzyl benzoate and the subsequent hydrolysis of the ester. It has been stated that acetaldehyde in the presence of aluminium ethylate is converted into ethylacetate (**189**) by what is apparently a similar kind of condensation.

Benzyl alcohol resembles ethyl alcohol in chemical properties. It yields an aldehyde and an acid on oxidation, is converted

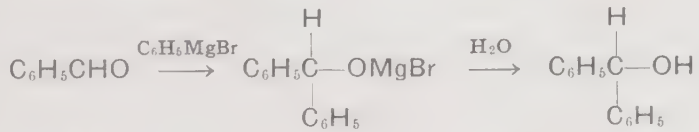
into benzyl chloride by the chlorides of phosphorus, and forms esters with acids. The presence of the phenyl radical affects to some extent the activity of the alcohol. For example, benzyl alcohol is converted into benzyl chloride by cold concentrated hydrochloric acid, whereas ethyl alcohol is not changed under the same conditions. The alcohol does not yield benzylsulphuric acid when treated with concentrated sulphuric acid, but a resin is formed, which probably results from the elimination of water from the alcohol.

p-Hydroxybenzyl alcohol is formed as the result of the combination of phenol, C_6H_5OH, and formaldehyde in aqueous solution in the presence of a base. When the alcohol is heated it condenses to a resin, one variety of which is known as *bakelite*. On account of the reactivity of benzyl alcohol, its derivatives which contain substituents in the ring are prepared indirectly. Thus, *m*-nitrobenzyl alcohol is not formed when benzyl alcohol is treated with nitric acid. It is prepared by the action of sodium hydroxide on *m*-nitrobenzoic aldehyde.

537. Diphenylcarbinol (benzohydrol), $(C_6H_5)_2CHOH$, is an example of a secondary aromatic alcohol. It resembles in chemical properties the analogous aliphatic alcohols, but the presence of the two aryl radicals brings about an activity which is not observed among the derivatives of the paraffins. Diphenylcarbinol is made most conveniently by reducing benzophenone with zinc and an alcoholic solution of potassium hydroxide:

$$(C_6H_5)_2CO + 2H = (C_6H_5)_2CHOH$$

Diphenylcarbinol may be prepared by the Grignard reaction. The steps involved in the preparation are indicated by the following formulas:



This method has been of service in the preparation of a number of compounds analogous to diphenylcarbinol.

Diphenylcarbinol melts at 68° and boils at 298.5°. Oxidizing agents convert it into benzophenone, and a concentrated solution of hydrochloric acid into diphenylchloromethane.

538. Triphenylcarbinol, $(C_6H_5)_3COH$, possesses the properties characteristic of a tertiary alcohol. Like other compounds of this class, it is converted into a chloride when treated with acid chlorides, and not into an ester:

$$(C_6H_5)_3COH + CH_3COCl = (C_6H_5)_3CCl + CH_3COOH$$

Triphenylcarbinol can be prepared by oxidizing triphenylmethane:

$$(C_6H_5)_3CH + O = (C_6H_5)_3COH$$

The preparation is carried out by heating a solution of the hydrocarbon in acetic acid with chromic acid. This method of preparing a tertiary alcohol is limited in its application to the aromatic series.

The alcohol is conveniently prepared by heating triphenylchloromethane (**498**) with water:

$$(C_6H_5)_3CCl + HOH = (C_6H_5)_3COH + HCl$$

Triphenylcarbinol melts at 162.5°, and boils without decomposition above 360°.

539. Cinnamyl alcohol, $C_6H_5.CH{=}CH.CH_2OH$, may be taken as an example of the unsaturated aromatic alcohols. It occurs in storax as the ester of cinnamic acid, $C_6H_5CH{=}CHCOOH$. It crystallizes in needles, which possess an odor like that of hyacinths, melts at 33°, and boils at 258.5°.

The chemical properties of the alcohol are in accord with the structure assigned to it. It is converted by reduction into 3-phenyl-1-propanol:

$$C_6H_5.CH:CH.CH_2OH + 2H = C_6H_5.CH_2.CH_2.CH_2OH$$

The product formed when the alcohol is oxidized is determined by the oxidizing agent used. Air in the presence of platinum-black gives cinnamic aldehyde:

$$C_6H_5.CH:CH.CH_2OH + O = C_6H_5.CH:CH.CHO + H_2O$$

and chromic acid gives cinnamic acid and benzoic acid:

$$C_6H_5.CH:CH.CH_2OH + 2\,O = C_6H_5.CH:CH.COOH + H_2O$$

$$C_6H_5.CH:CH.CH_2OH + 7O = C_6H_5COOH + 2CO_2 + 2H_2O$$

Cinnamic acid is formed as the result of the oxidation of a primary alcohol group to the carboxyl group, and benzoic acid as the result of the complete oxidation of the side chain.

Phenols

540. The phenols are not usually made by the methods used in the preparation of alcohols, as halogen atoms linked to carbon atoms of the benzene ring cannot, in general, be replaced readily by hydroxyl groups.

Phenols are prepared from sulphonic acids or amines. When the sodium salt of benzenesulphonic acid, for example, is fused with sodium hydroxide, it is converted into the salt of phenol:

$$C_6H_5SO_3Na + 2NaOH = C_6H_5ONa + Na_2SO_3 + H_2O$$

Phenol is obtained by treating the product of the fusion with an acid:

$$C_6H_5ONa + HCl = C_6H_5OH + NaCl$$

The reaction is one which is extensively used in the preparation of compounds of this class.

Phenols are also prepared from primary amines by means of the diazo reaction:

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O$$
$$C_6H_5N_2Cl + HOH = C_6H_5OH + N_2 + HCl$$

541. Chemical Properties of Phenols.—Phenols exhibit the behavior of hydroxyl compounds when treated with the substances which react with the hydroxyl group. They react with acyl chlorides and acid anhydrides. Phenol and acetyl chloride, for example, react and form phenyl acetate and hydrogen chloride:

$$CH_3COCl + HOC_6H_5 = CH_3COOC_6H_5 + HCl$$

The hydroxyl group of phenols can be replaced by halogen by means of the halides of phosphorus:

$$C_6H_5OH + PCl_5 = C_6H_5Cl + POCl_3 + HCl$$

The yield of chloride obtained in this way is small, however, as the chief product of the reaction consists of esters of phosphoric acid and compounds formed by the replacement of one or more

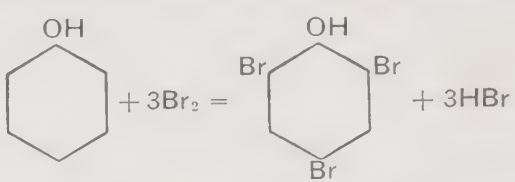
halogen atoms by the C_6H_5O group. The compounds formed when phosphorus trichloride is used, have the formulas

$$(C_6H_5O)_3P, \quad (C_6H_5O)_2PCl, \quad \text{and} \quad (C_6H_5O)PCl_2.$$

Salts of phenols react with alkyl halides and form ethers:

$$C_6H_5OK + C_2H_5I = C_6H_5OC_2H_5 + KI,$$

Substitution products of phenols are readily prepared, the presence of the hydroxyl group facilitating markedly the introduction of atoms or groups. An aqueous solution of bromine converts phenol into symmetrical tribromophenol:



Dilute nitric acid gives *o*-nitrophenol and *p*-nitrophenol, and the concentrated acid symmetrical trinitrophenol.

Phenols are reduced to hydrocarbons when passed over heated zinc dust:

$$C_6H_5OH + Zn = C_6H_6 + ZnO$$

It has been stated that phenols are weak acids; their salts are decomposed by carbonic acid. The extent to which acetic acid, carbonic acid, and phenol dissociate in one-tenth normal solution is 1.3, 0.174, and 0.0037 per cent, respectively, whereas at this concentration hydrochloric acid is dissociated to the extent of over 90 per cent. Notwithstanding the fact that phenols are such weak acids, they dissolve readily in alkalies. As they are weaker than carbonic acid, they are not soluble in carbonates. This fact is made use of in the separation of acids from phenols.

The acidic property of phenols is increased as the result of the replacement of the hydrogen atoms which they contain by certain atoms or groups. Trinitrophenol is a comparatively strong acid, which readily decomposes carbonates.

542. Phenol, C_6H_5OH, occurs in coal tar. It is found in the urine in small quantities in combination with sulphuric acid as phenylsulphuric acid, $C_6H_5SO_4H$. It is a colorless substance

which crystallizes in long needles, melts at 41°, and boils at 182°. Phenol, sometimes called "carbolic acid," has a characteristic odor, and on account of its strong antiseptic properties was formerly much used in surgery. Phenol dissolves in about 15 parts of water at 16°. Water is slightly soluble in phenol. The presence of even a small amount of water lowers the freezing point of phenol below the ordinary temperature. Phenol is used in the manufacture of resins (**536**).

Large quantities of phenol are obtained from coal tar; it is manufactured either from sodium benzenesulphonate or from chlorobenzene. In the latter process, which has been developed recently, chlorobenzene and a solution of sodium hydroxide are slowly passed through copper tubes under pressure and at an elevated temperature; the sodium phenolate, C_6H_5ONa, formed in this way is converted into phenol when the solution is acidified. Diphenyl ether, $C_6H_5OC_6H_5$, is a by-product (**555**). By modifying the conditions under which reaction takes place *orthohydroxybiphenyl* and *parahydroxybiphenyl*, $C_6H_5.C_6H_4OH$, can be prepared. The former compound is a valuable antiseptic; the latter yields a resin of the bakelite type (**536**), when condensed with formaldehyde.

The more important reactions of phenol have been given in the section above. Phenol is a poison, and has a corrosive action on the skin. Ferric chloride produces a violet coloration in a dilute aqueous solution of phenol. It is of interest to note that phenol has been prepared from benzene by the action of oxygen in the presence of palladium black or aluminium chloride.

543. Cresols, $CH_3.C_6H_4.OH$.—The three hydroxyl derivatives of toluene are found along with other phenols in the *creosote* obtained from coal tar, and in the tars from pine and beech wood. As it is difficult to separate the isomeric cresols they are prepared in the pure condition from the toluenesulphonic acids or the toluidines.

o-Cresol (m.p. 30.1°, b.p. 190.8°) and *p*-cresol (m.p. 34.8°, b.p. 201.1°) are decomposition products of proteins. The ortho compound has been found in combination with sulphuric acid in the urine of horses, and the para compound in the urine of man. *o*-Cresol has high bactericidal powers and is used as a germicide and antiseptic.

544. Carvacrol and thymol, $CH_3.C_3H_7.C_6H_3.OH$, are phenols derived from cymene (*p*-methyl-isopropylbenzene). In carvacrol the hydroxyl group is ortho to the methyl radical; this is shown by the fact that carvacrol is converted into *o*-cresol and propylene when heated with phosphorus pentoxide. In thymol the hydroxyl group is ortho to isopropyl.

Carvacrol occurs with cymene in a number of essential oils. It can be prepared by heating camphor with iodine. Thymol occurs in the oil of thyme and the oil of mint. It has germicidal properties, but is less active and less poisonous than phenol.

545. Naphthols, $C_{10}H_7OH$.—The naphthols are prepared by fusing the isomeric naphthalenesulphonic acids with alkalies. They crystallize in plates, have a phenolic odor, and are sparingly soluble in water. 1- or α-Naphthol melts at 96° and boils at 280°; 2- or β-naphthol melts at 122° and boils at 286°. Although the naphthols possess the properties of phenols, the hydroxyl groups which they contain are more readily replaceable by other groups than is the hydroxyl group of phenol. For example, when β-naphthol is heated with the compound of calcium chloride and ammonia, it is converted into β-naphthylamine (**513**).

The naphthols react with sodium bisulphite when heated in aqueous solution under pressure:

$$C_{10}H_7OH + NaHSO_3 = C_{10}H_7OSO_2Na + H_2O$$

The ester formed in this way is converted into naphthylamine when heated with ammonia (**513**):

$$C_{10}H_7OSO_2Na + NH_3 = C_{10}H_7NH_2 + NaHSO_3$$

These reactions are used industrially.

When ferric chloride is added to a solution of β-naphthol a green coloration and a precipitate of a bi-β-naphthol, $HO.C_{10}H_6.C_{10}H_6.OH$, are formed; with α-naphthol a violet precipitate, which is probably an iron compound of a bi-α-naphthol, results. β-Naphthol is used as an antiseptic.

546. Pyrocatechol (pyrocatechin, catechol), $C_6H_4(OH)_2(1, 2)$, occurs in the leaves and sap of certain plants, in raw beet sugar, and in many resins. It is obtained by heating guaiacol, $C_6H_4OH.OCH_3(1, 2)$, which is a constituent of beech-wood tar, with hydriodic acid. It is also prepared by fusing *o*-phenolsulphonic acid with potassium hydroxide at 350°. Pyrocatechol is readily

soluble in water, from which it crystallizes in needles, which melt at 105°.

An alkaline solution of pyrocatechol absorbs oxygen from the air, and turns green and then black. The solution precipitates the metals from salts of silver, gold, and platinum; on account of this fact it is used as a photographic developer. An aqueous solution of the phenol is colored green by ferric chloride. When an alkali is added to the solution the color changes to red as the result of the formation of a salt of the composition $Na_3Fe(C_6H_4O_2)_3.2H_2O$. The iron in this compound is not precipitated by bases. As the radical of pyrocatechol is bivalent the salt resembles in composition sodium ferricyanide, $Na_3Fe(CN)_6$.

547. Resorcinol (resorcin), $C_6H_4(OH)_2(1, 3)$, is prepared technically by fusing *m*-benzenedisulphonic acid with caustic soda. It is also formed when *m*-iodophenol or *p*-chlorobenzenesulphonic acid is fused with potassium hydroxide. The preparation of resorcinol from these compounds illustrates two important points: first, that a halogen atom in direct combination with the benzene ring may be replaced by hydroxyl; and second, that in effecting the replacement of one group by another by means of fusion with an alkali, the relative positions of the groups in the resulting compound may not be those of the groups in the substance used in the synthesis. Many ortho, meta, and para compounds yield resorcinol when fused with caustic alkalies. This unexpected result is not in accord with one of the important principles made use of in the determination of structure, and led to much confusion in the early study of organic chemistry.

Resorcinol crystallizes from water in colorless plates or prisms, which melt at 110°, and turn red in the air. It gives a deep-violet coloration with a solution of ferric chloride. The phenol is not as strong a reducing agent as pyrocatechol.

Resorcinol is used in the manufacture of certain dyes. When heated with sodium nitrite it yields a blue dye, called *lacmoid*, which is turned red by acids.

Heryl-resorcinol, $(OH)_2(1, 3)C_6H_{13}(4)$ is used as an antiseptic.

548. Hydroquinone (quinol), $C_6H_4(OH)_2(1,4)$, may be obtained from arbutin, which is a glucoside of hydroquinone, by hydrolysis with dilute acids, or by the action of emulsin. It is prepared

by reducing quinone, $C_6H_4O_2$ (**597**), by means of sulphur dioxide and water.

Hydroquinone is readily soluble in water, from which it crystallizes in prisms which melt at 170.5°. It can be sublimed unchanged. An aqueous solution of hydroquinone slowly turns brown when exposed to the air and loses its reducing power. As a reducing agent it is intermediate between pyrocatechol and resorcinol. An alkaline solution of hydroquinone is a valuable photographic developer. Oxidizing agents convert hydroquinone into quinone; the reaction will be considered later (**597**). When ferric chloride is added to an aqueous solution of the phenol, quinhydrone (**597**) separates in lustrous green spangles. On adding an excess of ferric chloride the quinhydrone is converted into quinone.

549. Pyrogallol (pyrogallic acid), $C_6H_3(OH)_3(1, 2, 3)$, is the most important of the isomeric trihydroxybenzenes. It is obtained by heating gallic acid (**633**):

$$C_6H_2(OH)_3COOH = C_6H_3(OH)_3 + CO_2$$

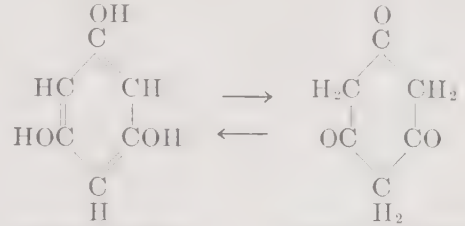
It is readily soluble in water, crystallizes in colorless plates, which melt at 134°, and can be sublimed without decomposition. It is an energetic reducing agent and is used as a photographic developer. An alkaline solution of pyrogallic acid absorbs oxygen from the air and rapidly turns brown. Such solutions are used in the determination of oxygen in gas analysis.

550. Phloroglucinol (phloroglucin), $C_6H_3(OH)_3(1, 3, 5)$, was first obtained from the glucoside phlorizin. It has also been isolated from other glucosides and from certain resins. It is formed when resorcinol, orcinol (3, 5-dihydroxytoluene), or 1, 3, 5-benzene-trisulphonic acid is fused with sodium hydroxide. The formation of phloroglucinol from resorcinol is an illustration of a reaction which often takes place in fusion with alkalies, namely, the replacement of a hydrogen atom by a hydroxyl group. The formation of the phenol from orcinol under the same conditions, is effected as the result of the replacement of an alkyl radical by hydroxyl. Under certain conditions alkyl radicals joined to the benzene ring are converted into carboxyl groups when the compounds which contain the radical are fused with alkalies. *p*-Toluenesulphonic acid may be converted in this way into *p*-hydroxybenzoic acid. These illustrations indi

cate that fused alkalies are active reagents which serve to bring about many important transformations in aromatic compounds.

Phloroglucinol melts at 219° and tastes sweet. An aqueous solution of the phenol is colored bluish-violet by ferric chloride.

551. Many of the reactions of phloroglucinol are in accord with the view that it is a trihydroxyl derivative of benzene. With certain reagents, however, it reacts as if it were a ketone which contains three carbonyl groups. For example, one molecule of phloroglucinol reacts with three molecules of hydroxylamine, and a compound is formed which has the properties characteristic of oximes. These facts are explained by the hypothesis that the compound can exist in the two tautomeric forms represented by the following formulas:



Trihydroxybenzene Triketocyclohexane

The behavior of phloroglucinol with reagents is analogous to that of other tautomers. When brought into contact with reagents which interact with hydroxyl derivatives, it reacts as if it contained this group, and with certain substances which interact with ketones, it acts as if it belonged to the latter class of compounds. This view of the structure of phloroglucinol furnishes an explanation of the fact that when a solution of the phenol in potassium hydroxide is treated with alkyl iodides, compounds are formed in which the alkyl radicals are linked to carbon. The relation between the two forms of phloroglucinol is similar to that between the *enol* and *keto* forms of acetoacetic ester. It will be recalled that when the sodium derivative of the *enol* form of the ester is treated with alkyl halides, the product of the reaction is a derivative of the *keto* form in which the alkyl group introduced is linked to carbon. Tautomerism is shown by many compounds which contain the group —CO—CH_2—, the rearrangement taking place as indicated below:

The trihydroxybenzene which has the unsymmetrical structure $C_6H_3(OH)_3$(1, 2, 4) is called *hydroxyhydroquinone*. It can be prepared by fusing hydroquinone with potassium hydroxide. Like pyrogallol it does not react with hydroxylamine.

552. Hexahydroxybenzene, $C_6(OH)_6$, is obtained from its potassium salt, which is formed by passing carbon monoxide over heated potassium:

$$6CO + 6K = C_6(OK)_6$$

The compound forms colorless crystals, which are readily oxidized by the air. It is converted into benzene when distilled with zinc dust.

553. Identification of Phenols.—The reactions of phenols which are of particular value in their identification, are those that take place with alkalies, ferric chloride, and bromine water. Most phenols react with an aqueous solution of sodium hydroxide to form soluble salts, but are insoluble in a solution of sodium carbonate. The behavior of phenols with these two reagents shows their weakly acidic properties, and serves to distinguish them from acids. Phenols which contain strongly negative substituents decompose carbonates and show all the properties of acids. It is difficult, therefore, to identify as phenols substances which contain such substituents. Ferric chloride produces marked colorations in aqueous solutions of most phenols. The reagent produces a similar effect with certain other compounds, and the formation of a color with ferric chloride can be taken, therefore, only as an indication of the presence of a phenol. With bromine water most phenols yield a precipitate of a brominated phenol. Other compounds, amines for example, are also converted into insoluble substitution products by bromine water. Notwithstanding this fact the test is of value. Many phenols form colored products when heated with phthalic anhydride and concentrated sulphuric acid. The reaction will be described under phenolphthalein (**574, 668**).

Ethers

554. The aromatic ethers may be divided into two classes, *viz.*, those which contain an aryl and an alkyl radical, and those which contain two aryl radicals. The ethers of the first class resemble closely the analogous aliphatic compounds and can be made by similar methods.

Anisole, phenyl methyl ether, $C_6H_5OCH_3$, can be prepared by treating a solution of phenol in potassium hydroxide with methyl iodide:

$$C_6H_5OK + CH_3I = C_6H_5OCH_3 + KI$$

In the preparation in this way the halogen is removed from an aliphatic compound, and the reaction takes place readily. In order to prepare anisole from bromobenzene by the reaction

$$C_6H_5Br + NaOCH_3 = C_6H_5OCH_3 + NaBr$$

it is necessary to heat the mixture for a long time in a sealed tube at 220° or to expose it to the action of ultraviolet light at room temperatures. The two reactions show very clearly the difference in reactivity between alkyl and aryl halides. Anisole is a liquid of ethereal odor, which boils at 155.8°.

Anisole is also formed by a reaction which is characteristic of the aromatic series, namely, the decomposition of a diazonium salt with an alcohol:

$$C_6H_5N_2Cl + CH_3OH = C_6H_5OCH_3 + N_2 + HCl$$

Like aliphatic ethers, the aromatic ethers are stable compounds; they are decomposed, however, when heated with hydriodic acid:

$$C_6H_5OCH_3 + HI = C_6H_5OH + CH_3I$$

Phenetole, phenyl ethyl ether, $C_6H_5OC_2H_5$, boils at 172°, the boiling point being lower than that of phenol.

555. Phenyl Ether.—The ethers which contain two aryl radicals cannot be made by the general method employed to prepare other ethers, as the aryl halides do not react readily with the salts of phenols. Phenyl ether is obtained by heating phenol with anhydrous zinc chloride:

$$C_6H_5OH + HOC_6H_5 = C_6H_5OC_6H_5 + H_2O$$

It can also be prepared by passing the vapor of phenol through a hot tube which contains thorium oxide. This oxide has been found to be of particular value as a catalyst at elevated temperatures in reactions involving the hydroxyl group. Phenyl ether is a very stable compound. It is not decomposed when heated with hydriodic acid to a high temperature. Phenyl ether melts at 26.9° and boils at 259°.

Phenyl ether is a by-product in the manufacture of phenol (**542**). By changing the conditions under which the process is carried out it can be made the chief product. On account of its stability it can be used as a substitute for water in boilers designed to operate at high temperatures in the production of power.

Problems

1. Write equations for reactions by which the following can be prepared from benzene: (*a*) *p*-$ClC_6H_4CH_2OH$; (*b*) *p*-$ClC_6H_4CHOHC_6H_5$; (*c*) C_6H_5-

$CHOHCH_3$; (*d*) *p*-$CH_3C_6H_4CHOHC_6H_5$; (*e*) $(p\text{-}BrC_6H_4)_3COH$; (*f*) *p*-$CH_3C_6H_4OH$; (*g*) *m*-$C_6H_4(OH)_2$; (*h*) $C_6H_5OC_5H_{11}$.

2. By what reactions could the following be converted into the corresponding hydrocarbon: (*a*) *p*-$CH_3C_6H_4OH$; (*b*) $C_6H_5SO_3H$; (*c*) $CH_3C_6H_4COOH$; (*d*) $C_6H_5OC_2H_5$; (*e*) $C_6H_4(OH)_2$; (*f*) $NH_2C_6H_4OCH_3$; (*g*) $CH_3C_6H_4NO_2$?

3. By what chemical tests could the following be distinguished: (*a*) $CH_3C_6H_4OH$ and $C_6H_5CH_2OH$; (*b*) $C_6H_4(OH)_2$ and $CH_3OC_6H_4OH$; (*c*) $CH_3C_6H_4OH$ and $C_6H_5OCH_3$; (*d*) *p*-OHC_6H_4COOH, C_6H_5COOH and C_6H_5OH; (*e*) $C_6H_5COOCH_3$ and $C_6H_5OCH_3$; (*f*) $CH_3OC_6H_4COOH$ and $HOC_6H_4COOCH_3$?

4. Identify the compound which gave the following results: The substance contained nitrogen, melted at 184°, and was slightly soluble in water. It dissolved in a solution of sodium hydroxide from which it was precipitated on the addition of hydrochloric acid. On further addition of acid the compound dissolved. It was reprecipitated when the acid was neutralized by sodium hydroxide. The substance did not react with sodium carbonate but was converted by acetyl chloride into a derivative that melted at 168°.

5. A number of drivatives of benzene were examined with the following results. State what groups are present in each:

a. The compound contains sulphur and liberates CO_2 from a solution of sodium carbonate.

b. The compound dissolved in a solution of sodium hydroxide but not in one of sodium carbonate.

c. The compound contains nitrogen, is insoluble in water, soluble in a solution of sodium hydroxide, insoluble in a solution of sodium carbonate, and soluble in dilute hydrochloric acid.

d. The compound dissolves in concentrated sulphuric acid and, when boiled with a concentrated solution of hydriodic acid, yields methyl iodide.

e. The compound reacts with sodium and is insoluble in a solution of sodium hydroxide.

CHAPTER XXIV

AROMATIC ACIDS

556. The aromatic acids resemble closely in chemical properties the acids derived from the paraffins and yield similar derivatives. On account of the presence of aryl radicals they are stronger than the fatty acids. The ionization constant of benzoic acid, $C_6H_5.COOH$, for example, is 6.1×10^{-5}, while that of acetic acid is 1.8×10^{-5}.

The presence of a benzene ring in these acids makes it possible to prepare from them many derivatives which are characteristic of aromatic compounds. Benzoic acid is converted into nitrobenzoic acid by nitric acid and into a sulphonic acid by sulphuric acid.

A large number of aromatic acids occur in nature in the free condition and as esters in resins, balsams, and the oils extracted from plants. They also occur in the animal organism in combination with nitrogenous substances. The acids are, in general, colorless and crystalline, difficultly soluble in water, and may be distilled or sublimed unchanged. Those which contain a number of carboxyl or hydroxyl groups decompose when heated to a high temperature; gallic acid, $C_6H_2(OH)_3COOH$, for example, loses carbon dioxide when heated, and is converted into pyrogallol, $C_6H_3(OH)_3$.

557. Preparation of Aromatic Acids.—The aromatic acids may be formed by methods which are analogous to those used in the preparation of fatty acids. *Aromatic alcohols and aldehydes yield acids on oxidation:*

$$C_6H_5.CH_2OH + 2O = C_6H_5.COOH + H_2O$$
$$C_6H_5.CHO + O = C_6H_5.COOH$$

These methods are seldom used as the acids can be prepared more conveniently in other ways.

Acids are frequently made by hydrolyzing nitriles:

$$C_6H_5.CN + 2H_2O = C_6H_5.COOH + NH_3$$
$$C_6H_5.CH_2.CN + 2H_2O = C_6H_5.CH_2.COOH + NH_3$$

Nitriles which contain the CN group in the side chain are prepared as in the aliphatic series; those in which the group is linked to the nucleus are formed by means of the diazo reaction. This latter method of preparing acids is an important one, as by means of it a nitro or an amino group may be replaced by carboxyl.

Another important method is limited in its application to the preparation of acids which contain the carboxyl group in direct combination with the nucleus. *Aromatic acids* of this type *may be prepared by oxidizing aromatic hydrocarbons which contain side chains.* When toluene, for example, is heated with a solution of chromic acid, it is converted into benzoic acid:

$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$

All side chains, whatever their length, are converted by active oxidation into carboxyl groups:

$$C_6H_4\begin{matrix}CH_3\\C_3H_7\end{matrix} + 12O = C_6H_4\begin{matrix}COOH\\COOH\end{matrix} + 4H_2O + 2CO_2$$

It is possible under certain circumstances to bring about the oxidation of the side chains one after another. When *p*-xylene is heated with dilute nitric acid one methyl group is oxidized; chromic acid oxidizes both groups. It is thus possible to effect the transformations indicated by the following formulas:

$$C_6H_4\begin{matrix}CH_3\\CH_3\end{matrix} \longrightarrow C_6H_4\begin{matrix}CH_3\\COOH\end{matrix} \longrightarrow C_6H_4\begin{matrix}COOH\\COOH\end{matrix}$$

When halogen derivatives of benzene and its homologues are treated with ethyl chloroformate and sodium, esters are produced which on hydrolysis yield acids:

$$C_6H_5Br + ClCOOC_2H_5 + 2Na = C_6H_5COOC_2H_5 + NaCl + NaBr$$

Acids which contain the carboxyl group in a side chain may be prepared by the acetoacetic ester synthesis.

558. Chemical Properties of Aromatic Acids.—The aromatic acids take part in the reactions which are characteristic of the carboxyl group. They are converted, for example, into acyl halides by the halides of phosphorus,

$$C_6H_5.COOH + PCl_5 = C_6H_5.COCl + POCl_3 + HCl$$

and form esters when heated with alcohols in the presence of hydrogen chloride or sulphuric acid:

$$C_6H_5.COOH + C_2H_5OH = C_6H_5.COOC_2H_5 + H_2O$$

Like other aromatic compounds, they may be converted into nitro derivatives, sulphonic acids, and halogen derivatives. The presence of the carboxyl group makes it more or less difficult to introduce a negative substituent into the ring. While toluene, $C_6H_5.CH_3$, is readily sulphonated by warming the hydrocarbon with concentrated sulphuric acid on a water bath, benzoic acid, $C_6H_5.COOH$, is converted into a sulphonic acid by heating it with fuming sulphuric acid or sulphur trioxide. The carboxyl group sends a substituent to the meta position; benzoic acid yields on sulphonation *m*-sulphobenzoic acid, $HO_3S.C_6H_4COOH$, whereas toluene yields *p*-toluenesulphonic acid, $CH_3.C_6H_4.SO_3H$.

Monocarboxylic Acids and Their Derivatives

559. Benzoic acid, $C_6H_5.COOH$, occurs in gum benzoin, in many resins, in the balsams of Peru and Tolu, in cranberries, in coal tar, and in combination with glycine as hippuric acid in the urine of herbivorous animals. It may be made by the general synthetic methods which have been described. It is prepared for use in pharmacy by sublimation from gum-benzoin. It is manufactured on a large scale from toluene, and is a by-product in the preparation of benzaldehyde. Toluene is converted by direct oxidation into benzoic acid. As benzyl chloride, C_6H_5-CH_2Cl, is more readily oxidized than toluene, the latter is first treated with chlorine, and then heated with dilute nitric acid. It has been shown recently that if a mixture of air and the vapor of toluene is passed over vanadium oxide at about 400° the hydrocarbon is oxidized to benzoic acid.

Benzoic acid is also made from benzotrichloride, $C_6H_5.CCl_3$, which is prepared by passing chlorine into boiling toluene. When the halogen compound is heated with lime and water under pressure, the chlorine atoms are replaced by hydroxyl groups:

$$C_6H_5C\begin{matrix}Cl\\Cl\\Cl\end{matrix} + \begin{matrix}HOH\\HOH\\HOH\end{matrix} = 3HCl + C_6H_5C\begin{matrix}OH\\OH\\OH\end{matrix} \longrightarrow$$

$$C_6H_5C\begin{matrix}O\\\\OH\end{matrix} + H_2O$$

Benzoic acid is used in medicine, in the preparation of aniline blue, and for other purposes. Sodium benzoate is much used as a food preservative. The acid melts at 121.7°, boils at 249.2°, and sublimes readily. It crystallizes from hot water in glistening plates or flat needles, and is volatile with steam.

560. Benzoyl chloride, $C_6H_5.COCl$, can be prepared by the action of phosphorus pentachloride on benzoic acid or sodium benzoate. It is made on a large scale from benzoic aldehyde:

$$C_6H_5C\begin{matrix}H\\ \diagdown\\ \diagup\\ O\end{matrix} + Cl_2 = C_6H_5C\begin{matrix}Cl\\ \diagdown\\ \diagup\\ O\end{matrix} + HCl$$

Benzoyl chloride is a liquid of disagreeable odor, which is insoluble in water, and boils at 197°. It resembles acetyl chloride in its behavior, but does not enter into reaction so readily. It is decomposed but slowly by cold water or alcohol. The reaction between benzoyl chloride and alcohols is much facilitated by the presence of an alkali. Ethyl benzoate may be prepared by shaking an aqueous solution of alcohol and sodium hydroxide with benzoyl chloride (*Baumann and Schotten reaction*):

$$C_6H_5.COCl + HOC_2H_5 + NaOH = C_6H_5.COOC_2H_5 + NaCl + H_2O$$

561. Benzoic anhydride, $(C_6H_5CO)_2O$, can be prepared by the methods used to make acetic anhydride:

$$C_6H_5.COCl + C_6H_5COONa = (C_6H_5CO)_2O + NaCl$$

$$4C_6H_5COONa + POCl_3 = 2(C_6H_5CO)_2O + NaPO_3 + 3NaCl$$

The anhydride resembles acetic anhydride, but it is less active. It is converted slowly into benzoic acid by boiling water. It is insoluble in water and melts at 43°.

562. Benzamide, $C_6H_5CO.NH_2$, is formed when benzoyl chloride is treated with ammonium carbonate or an aqueous solution of ammonia. It crystallizes from hot water in glistening plates which melt at 130°.

563. The reactions of benzamide and other compounds of this class indicate that they may exist in two forms:

$$R{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}NH_2 \qquad \text{and} \qquad R{-}\overset{\displaystyle OH}{\overset{|}{C}}{=}NH$$

Certain derivatives of benzamide tend to confirm this view. When the silver salt of benzamide is treated with ethyl iodide, the metal is replaced

by the alkyl radical. The product formed is determined by the temperature at which reaction takes place. The substance obtained at room temperature yields ammonia and has the formula given below. It belongs to the class of compounds known as *iminoesters*, which may be considered as derived from esters by the replacement of the oxygen atom of the carbonyl group by the bivalent imino group, =NH. Like esters it yields an alcohol on hydrolysis; at the same time the imino group is replaced by oxygen.

$$C_6H_5C(OC_2H_5):NH + 2H_2O = C_6H_5C(OH):O + C_2H_5OH + NH_3$$

The compound formed from the silver salt of benzamide and ethyl iodide at 100° is a substitution product of the amide in which the alkyl group is joined to nitrogen. Like other amides of this class it yields on hydrolysis an acid and an amine:

$$C_6H_5C(=O)—NHC_2H_5 + H_2O = C_6H_5C(=O)—OH + C_2H_5NH_2$$

564. Benzonitrile, $C_6H_5.CN$, can be prepared by a method used to make acetonitrile, namely, the removal of water from benzamide or by heating potassium benzenesulphonate with potassium cyanide. The method most commonly used in the preparation of the nitriles of aromatic acid is an application of the diazo reaction (**527**). Benzonitrile is a liquid with an odor resembling that of the oil of bitter almonds. It boils at 190.7°, and is converted into benzoic acid when heated with a mixture of 1 part of water and 3 parts of sulphuric acid.

565. Toluic Acids, $CH_3.C_6H_4.COOH$.—The three toluic acids can be prepared by the oxidation of the three xylenes with nitric acid, or from the toluidines, $CH_3.C_6H_4.NH_2$, by converting them by means of the diazo reaction into nitriles, which on hydrolysis are converted into toluic acids. The acids are crystalline substances which are difficultly soluble in water. The ortho, meta, and para acids melt at 102.4°, 110.5°, and 176.8°, respectively.

566. Phenylacetic acid, $C_6H_5.CH_2.COOH$, is isomeric with the toluic acids. It is prepared by hydrolyzing benzyl cyanide (b.p. 233.9°), which is formed by the action of potassium cyanide on benzyl chloride:

$$C_6H_5.CH_2Cl + KCN = C_6H_5.CH_2CN + KCl$$

$$C_6H_5.CH_2.CN + 2H_2O = C_6H_5.CH_2.COOH + NH_3$$

Phenylacetic acid crystallizes in lustrous plates and melts at 76°. It is converted by oxidizing agents into benzoic acid, whereas the isomeric toluic acids are converted into phthalic acids:

$$C_6H_5CH_2COOH + 3O = C_6H_5COOH + CO_2 + H_2O$$

$$C_6H_4\begin{<}{CH_3}{COOH}\ + 3O = C_6H_4\begin{<}{COOH}{COOH}\ + H_2O$$

Phenylacetic acid yields derivatives which contain substituents in either the side chain or the nucleus. The methods by which the two classes of derivatives may be prepared are applications of the principles which have been discussed. The reactions by which the two chlorine substitution products are formed are examples:

$$C_6H_5.CHOH.COOH + HCl = C_6H_5.CHCl.COOH + H_2O$$

$$ClC_6H_4.CH_2.CN + 2H_2O = ClC_6H_4.CH_2.COOH + NH_3$$

567. Cinnamic acid, $C_6H_5.CH{=}CH.COOH$, is the most important member of the class of unsaturated aromatic acids. It occurs in oil of cinnamon, the balsams of Peru and Tolu, gum benzoin, storax, and the leaves of certain plants. The acid crystallizes from hot water, melts at 133°, and boils with partial decomposition at 300°.

Cinnamic acid is manufactured by the so-called *Perkin synthesis*, which has been applied to the preparation of a large number of unsaturated acids. When benzoic aldehyde is heated with anhydrous sodium acetate in the presence of acetic anhydride, condensation takes place as the result of the loss of water:

$$C_6H_5.CHO + CH_3.COONa = C_6H_5.CH:CH.COONa + H_2O$$

568. A similar condensation takes place between benzoic aldehyde and homologues of acetic acid. The hydrogen atoms which are eliminated from the salt of the fatty acid are those in the α-position:

$$C_6H_5.CHO + CH_3.CH_2.COONa = C_6H_5CH:\overset{CH_3}{\overset{|}{C}}.COONa + H_2O$$

It has been shown that the formation of unsaturated acids by the Perkin synthesis takes place as the result of two reactions. The aldehyde and the

salt first form an addition product, which resembles in structure other addition products of aldehydes:

$$C_6H_5.\underset{\underset{O}{\|}}{\overset{\overset{H}{|}}{C}} + CH_3.COONa = C_6H_5.\underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}}—CH_2.COONa$$

In the addition, one hydrogen atom unites with the oxygen and the rest of the molecule with carbon. The second step in the reaction involves the removal of water from a β-hydroxy acid. It will be recalled that such acids readily lose water and pass into unsaturated acids:

$$C_6H_5.CHOH.CH_2COONa = C_6H_5CH : CH.COONa + H_2O$$

569. Cinnamic acid can also be prepared by heating benzal chloride with sodium acetate—a method which is applied commercially:

$$C_6H_5.CHCl_2 + CH_3COONa = C_6H_5.CH : CH.COOH + NaCl + HCl$$

Cinnamic acid, like other unsaturated compounds, forms addition products with the halogen hydrides, hypochlorous acid, bromine, etc. It yields esters, an acid chloride, and an amide. The hydrogen atoms in the benzene ring may be replaced by the halogens, nitro groups, amino groups, and the sulphonic acid group.

570. The formula of cinnamic acid leads to the view that it should exist in two stereochemical modifications, which bear a relation to each other similar to that shown in the case of fumaric and maleic acids. The stereoisomer melts at 57° and is called *allocinnamic acid:* it has been shown to be the *cis* modification (**81**).

For some time four modifications of cinnamic acid, which possess different melting points, have been known. It has been shown that three of the forms, which melt at 68°, 57°, and 42°, respectively, are crystallographic modifications of a single acid. When any one of them is melted and the liquid formed is seeded with a crystal, the solid which separates on cooling has the melting point of the crystal used to induce crystallization. The fact that apparently four forms of the acid exist aroused much interest and led to a number of investigations, because the results appeared to be at variance with the accepted theory as to the structure of organic compounds.

571. Phenylpropiolic acid, $C_6H_5.C\equiv C.COOH$, may be prepared from cinnamic acid by the reactions which are commonly employed to establish a triple bond in a compound. It is obtained by adding bromine to the ethyl ester of cinnamic acid,

and subsequent elimination of hydrogen bromide by alcoholic potassium hydroxide:

$$C_6H_5.CH:CH.COOC_2H_5 + Br_2 = C_6H_5.CHBr.CHBr.COOC_2H_5$$

$$C_6H_5.CHBr.CHBr.COOC_2H_5 + 3KOH = C_6H_5.C:C.COOK + 2KBr + 2H_2O + C_2H_5OH$$

Phenylpropiolic acid melts at 137° and crystallizes in needles which can be sublimed. When heated with water at 120° it loses carbon dioxide, and phenylacetylene is formed:

$$C_6H_5.C:C.COOH = C_6H_5.C:CH + CO_2$$

Dicarboxylic Acids and Their Derivatives

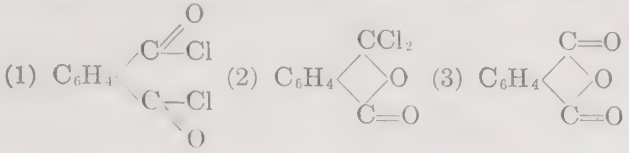
572. The dicarboxylic acids derived from benzene are the most important members of this class. They are called phthalic acids on account of the fact that the first of them discovered was prepared from naphthalene. The chemistry of the aromatic acids is similar to that of the analogous fatty compounds. In addition to the chemical properties possessed by the latter, the phthalic acids possess the properties characteristic of aromatic compounds, *i.e.*, they may be nitrated, sulphonated, and chlorinated.

Phthalic acid, $C_6H_4(COOH)_2(1, 2)$, is formed when benzene derivatives which contain two side chains in the ortho position, are oxidized by dilute nitric acid or potassium permanganate. Chromic acid cannot be used, as it oxidizes ortho compounds completely to carbon dioxide and water. The acid is prepared on a large scale from naphthalene. The hydrocarbon is oxidized by heating it with concentrated sulphuric acid in the presence of mercuric sulphate, which serves as a catalytic agent. The acid is prepared by the action of water on phthalic anhydride, which is manufactured from naphthalene by oxidation with the air (**574**).

Phthalic acid crystallizes from hot water. It does not possess a definite melting point, as it slowly decomposes into its anhydride and water when heated. Melting points can be obtained from 180° to 213°, the higher temperatures being observed when the acid is heated rapidly.

573. Phthalyl chloride is formed when phthalic acid is treated with phosphorus pentachloride. It has the structure represented by formula (1) below and melts at 16°. In certain of its reactions it behaves as if it

were the derivative of phthalic anhydride indicated by formula (2). The relation between the three compounds is indicated by the following formulas:



The compound having the structure indicated by formula (2) has been recently isolated; it melts at 89°. It readily changes into the phthalyl chloride with the normal structure [formula (1)] which, in turn, can be transformed into its isomer by aluminium chloride. The change also takes place when it is brought into reaction with certain other compounds. The two substances yield different compounds when treated with ammonia. In the case of the form which contains two chlorine atoms linked to the same carbon atom, the halogen is replaced by the =NH group and two molecules of hydrochloric acid are produced; in the case of the other form the product is *o*-cyanobenzoic acid, $C_6H_4CN.COOH$. The existence of these two chlorides is another example of desmotropy (**340**).

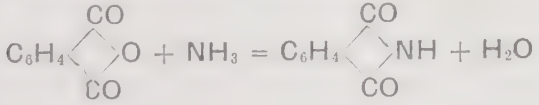
574. Phthalic anhydride, $C_6H_4(CO)_2O$, is formed when phthalic acid is heated. It is made on a large scale by passing the vapor of naphthalene and air over the oxide of vanadium at about 500°. It sublimes in long needles which melt at 130.8°. When heated with phenols in the presence of a dehydrating agent, phthalic anhydride forms characteristic compounds, called phthaleins (**667**), which give highly colored solutions when dissolved in alkalies.

When phthalic anhydride is heated with primary and secondary alcohols monoalkyl esters of phthalic acid are formed. Since many of these are crystalline solids their formation is useful in the identification of alcohols.

In the presence of a catalytic agent phthalic anhydride and alcohols form di-esters; dibutyl phthalate is a constituent of "duco," and diethyl phthalate is used as a denaturant for ethyl alcohol.

When glycerine is heated with phthalic anhydride a light-colored resin is formed, which has found a number of uses; it is called *glyptal*.

575. Phthalimide, $C_6H_4(CO)_2NH$, is obtained by passing ammonia over heated phthalic anhydride:



It crystallizes from ether in prisms, which melt at 238°. The imide is of interest on account of its use in the preparation of aliphatic amines. When phthalimide is treated in alcoholic solution with potassium hydroxide, a metallic derivative of the imide is precipitated. This salt interacts with alkyl halides to form compounds which are produced as the result of the replacement of the metal by the alkyl radicals. The substances formed in this way yield a primary amine on hydrolysis. The transformations involved are indicated by the following formulas:

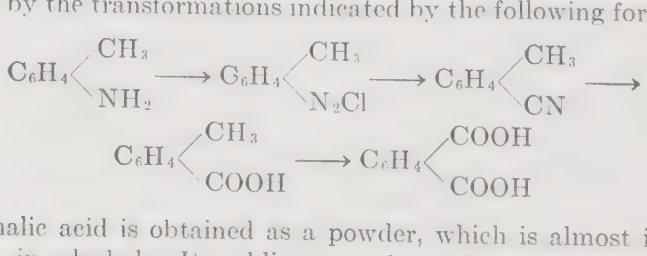
$$C_6H_4(CO)_2NK \xrightarrow{RI} C_6H_4(CO)_2NR \xrightarrow{NaOH} C_6H_4(COONa)_2 + H_2NR$$

It is possible to prepare by this method, which is known as *Gabriel's synthesis*, a great variety of primary amines, since substitution products of the alkyl halides, such as those of the formulas $CH_2Br.CH_2.CH_2Br$ and $CH_2OH.CH_2Br$, can be used in the synthesis

576. Isophthalic acid, $C_6H_4(COOH)_2$ (1, 3), may be formed from a large number of meta substitution products of benzene. It has been prepared by fusing the potassium salt of *m*-benzenedisulphonic acid with sodium formate, by the action of sodium and ethylchloroformate on *m*-dibromobenzene, by the oxidation of *m*-toluic acid, and in other ways. It is most conveniently prepared by oxidizing *m*-xylene with a solution of potassium dichromate and sulphuric acid. As in the oxidation of other hydrocarbons, the conversion of side chains into carboxyl groups proceeds more readily if a part of the hydrogen which they contain is replaced by halogen. In the preparation of isophthalic acid from *m*-xylene, the hydrocarbon is first heated with bromine at 125°, and the resulting substitution product, $C_6H_4(CH_2Br)_2$, is then oxidized.

Isophthalic acid crystallizes from hot water in needles, which melt at about 330°. It does not form an anhydride when heated.

577. Terephthalic acid, $C_6H_4(COOH)_2$(1, 4), can be formed from a number of para substitution products of benzene. It is conveniently prepared from *p*-toluidine by the transformations indicated by the following formulas:



Terephthalic acid is obtained as a powder, which is almost insoluble in water and in alcohol. It sublimes unchanged without melting. The property of certain dicarboxylic acids of forming anhydrides when heated is

limited to those acids which contain the two carboxyl groups in positions ortho to each other.

578. Mellitic acid, $C_6(COOH)_6$, is of interest as it contains six carboxyl groups. It occurs in peat as the aluminium salt, which is called "honeystone," $C_6(COO)_6Al_2.18H_2O$. The acid is formed as the result of the oxidation of lignite, wood charcoal, or graphite with potassium permanganate. It crystallizes in silky needles and is not affected when treated with nitric acid, sulphuric acid, or bromine. Benzene is formed when the calcium salt of mellitic acid is heated with lime.

Problems

1. Write equations for reactions by which aromatic acids may be prepared by six different methods.

2. Show by equations how the following acids may be prepared by the use of the Perkin synthesis: (*a*) $C_6H_5CH{=}C.CH_3.COOH$; (*b*) p-$CH_3C_6H_4CH{:}C(COOH)_2$; (*c*) o-$BrC_6H_4CH{=}CHCOOH$.

3. Show by equations how the following may be converted into benzoic acid: (*a*) $C_6H_5NH_2$; (*b*) $C_6H_5CONH_2$; (*c*) $C_6H_5C_5H_{11}$; (*d*) $(C_6H_5)_2CO$; (*e*) C_6H_5OH; (*f*) $C_6H_5CH_2CH_2OH$; (*g*) $C_6H_4(COOH)_2$; (*h*) C_6H_5Br; (*i*) $C_6H_5NO_2$; (*j*) $C_6H_5COOCH_3$.

4. Write equations for reactions by which the following can be prepared: (*a*) m-$NO_2C_6H_4COOH$; (*b*) p-$NO_2C_6H_4COOH$; (*c*) p-$NH_2C_6H_4SO_3H$; (*d*) o-ClC_6H_4COOH.

5. Calculate the number of cubic centimeters of a normal solution of sodium hydroxide required to neutralize 1 gm. of each of the following acids: (*a*) C_6H_5COOH, (*b*) $C_6H_4(COOH)_2$, and (*c*) $C_6H_5C_6H_4COOH$. (*d*) How could you distinguish these acids from one another by means of such a solution?

6. What would you expect to be the products formed when (*a*) the silver, (*b*) calcium, (*c*) copper, and (*d*) sodium salts of an organic acid are heated at a high temperature in the presence of air?

7. What substance could be conveniently prepared and studied in connection with the identification of a compound which appeared to be (*a*) benzoyl chloride, (*b*) phthalic anhydride, (*c*) benzonitrile, (*d*) benzamide, (*e*) phenol, (*f*) nitrobenzene.

CHAPTER XXV

AROMATIC ALDEHYDES, KETONES, AND QUINONES

579. The aromatic aldehydes are formed by reactions analogous to those made use of in the preparation of aliphatic aldehydes. The method which is best adapted to the preparation of the aromatic compounds is not the same as that used most conveniently in the aliphatic series. Acetic aldehyde and its homologues are usually prepared by oxidizing primary alcohols. Benzoic aldehyde, a typical aromatic aldehyde, is manufactured by heating benzal chloride, prepared from toluene, with water in the presence of lime:

$$C_6H_5.CHCl_2 + H_2O = C_6H_5.CHO + 2HCl$$

Acetic aldehyde can be formed in a similar way from ethylidene chloride, $CH_3.CHCl_2$, but its preparation by this reaction lacks practical value. There is a marked difference between the ease with which benzal chloride and ethylidene chloride react with water; the presence of the phenyl radical in the former brings about a reactivity not shown by the aliphatic halide.

The choice of the compounds used in the preparation of the two classes of aldehydes is determined, to some extent, by the substances which can be obtained conveniently and at a low price. The alcohols are in general the starting point for the preparation of many aliphatic compounds, on account of their reactivity and the fact that they are prepared commercially on a large scale. In the aromatic series, on the other hand, the hydrocarbons are of the greatest importance as a source of other compounds.

The aromatic aldehydes resemble in chemical properties the analogous aliphatic compounds; but their behavior with certain reagents is unique, and they enter into a number of reactions of condensation which are of prime importance. A description of a typical aldehyde will suffice to illustrate the properties of the members of the class.

580. Benzaldehyde (benzoic aldehyde), $C_6H_5.CHO$, occurs in amygdalin, a glucoside which is present in bitter almonds and in the kernels of various fruits; it yields the aldehyde, hydrocyanic acid, and glucose on hydrolysis (**373**). The aldehyde is called "oil of bitter almonds." It is used in flavoring extracts and perfumery, in the manufacture of certain dyes, and in the preparation of other compounds.

Benzaldehyde is a liquid with an agreeable odor, which boils at 179.5°, and has the specific gravity $1.046^{\frac{20}{4^\circ}}$. It can be formed by oxidizing benzyl alcohol, or by distilling calcium benzoate with calcium formate. It is manufactured by heating benzal chloride with milk of lime, or by oxidizing benzyl chloride with a solution of lead nitrate. It has been prepared from toluene directly by electrolytic oxidation or by oxidation with air in the presence of a catalyst.

Benzaldehyde shows most of the reactions which are characteristic of aliphatic aldehydes. It reduces an ammoniacal solution of silver nitrate, forms addition products with sodium hydrogen sulphite and with hydrocyanic acid, is converted by nascent hydrogen into an alcohol, and yields an oxime and a phenylhydrazone.

581. Benzaldehyde is oxidized when exposed to the air, the reaction taking place rapidly in the presence of sunlight. It has been shown that the first product formed is perbenzoic acid (benzoylhydro-peroxide), which results from the direct addition of one molecule of the aldehyde and one molecule of oxygen:

$$C_6H_5—\overset{\overset{O}{\|}}{C}H + O_2 = C_6H_5—\overset{\overset{O}{\|}}{C}—O—O—H$$

The peracid so formed is an active oxidizing agent and interacts with benzaldehyde to form benzoic acid:

$$C_6H_5.CO.O.OH + C_6H_5.CHO = 2C_6H_5.COOH$$

That an active oxidizing agent is formed during the oxidation of benzaldehyde by air, has been shown by adding to the aldehyde some oxidizable substance which is unaffected by free oxygen. The substance is oxidized and the amount of oxygen which reacts with it is equal to that used in converting the aldehyde into benzoic acid. One-half of the oxygen absorbed is thus rendered "active," *i.e.*, it has the properties of so-called nascent oxygen, being able to oxidize substances which are unaffected by molecular

oxygen. The phenomenon has been observed in the oxidation by air of various substances. Generally in such oxidations a molecule of oxygen is added to the compound and a peroxide is formed which in certain cases readily gives up a part of its oxygen to substances capable of undergoing oxidation.

582. In its reactions with alkalies and with ammonia, benzaldehyde does not resemble the aliphatic aldehydes. While the latter are converted into resins by alkalies, benzoic aldehyde and its homologues are converted by the reagent into alcohols and acids (Cannizzaro reaction, **536**):

$$2C_6H_5.CHO + KOH = C_6H_5.CH_2OH + C_6H_5.COOK$$

583. The aromatic aldehydes do not polymerize in the way which is characteristic of aliphatic aldehydes. Under certain conditions, however, two molecules of an aldehyde unite and form stable derivatives of dibenzyl. When benzaldehyde is heated in dilute alcoholic solution in the presence of potassium cyanide *benzoin* (**603**) is formed:

$$C_6H_5.\overset{\displaystyle H}{\underset{\displaystyle O}{\overset{|}{\underset{\|}{C}}}} + \overset{\displaystyle O}{\underset{\displaystyle H}{\overset{\|}{\underset{|}{C}}}}.C_6H_5 = C_6H_5.\overset{\displaystyle H}{\underset{\displaystyle OH}{\overset{|}{\underset{|}{C}}}}—\overset{\displaystyle O}{\overset{\|}{C}}.C_6H_5$$

The union of the two molecules is effected as the result of the breaking of the double bond of one of the carbonyl groups; a hydrogen atom adds to the oxygen, and the rest of the molecule to the carbon atom.

Benzaldehyde does not form an addition product with ammonia. When allowed to stand some days with a strong aqueous solution of ammonia, hydrobenzamide is formed:

$$3C_6H_5.CHO + 2NH_3 = (C_6H_5.CH)_3N_2 + 3H_2O$$

Hydrobenzamide is insoluble in water, and crystallizes from alcohol in octahedra, which melt at 101°.

584. When benzaldehyde is treated with chlorine, benzoyl chloride is formed:

$$C_6H_5.CHO + Cl_2 = C_6H_5.COCl + HCl$$

The reaction is used in the technical preparation of benzoyl chloride. The derivatives of benzaldehyde which contain a halogen atom in the ring are prepared from substitution products of benzal chloride:

$$Cl.C_6H_4.CHCl_2 + H_2O = Cl.C_6H_4.CHO + 2HCl$$

Benzaldehyde is converted by fuming sulphuric acid into *m*-sulphobenzaldehyde:

$$C_6H_5.CHO + H_2SO_4 = HO_3S.C_6H_4.CHO + H_2O$$

and by fuming nitric acid into *m*-nitrobenzaldehyde. *o*-Nitrobenzaldehyde is prepared by the careful oxidation of *o*-nitrocinnamic acid, $NO_2.C_6H_4CH{=}CH.COOH$; *p*-nitrobenzaldehyde may be made in a similar way.

585. *Condensation Reactions.*—Benzaldehyde takes part in a number of important condensations. When shaken with concentrated sulphuric acid and *aromatic hydrocarbons*, derivatives of triphenylmethane are formed:

$$C_6H_5.CHO + 2C_6H_5CH_3 = C_6H_5.CH(C_6H_4CH_3)_2 + H_2O$$

In the presence of dehydrating agents, such as zinc chloride, similar condensation products are formed from *phenols and aromatic amines:*

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

Benzaldehyde condenses with aliphatic compounds in an analogous manner; the Perkin synthesis (**567**) is an example:

$$C_6H_5.CHO + CH_3.COONa = C_6H_5CH:CH.COONa + H_2O$$

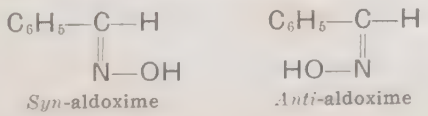
In the presence of a solution of sodium hydroxide benzaldehyde condenses with *aliphatic aldehydes and ketones:*

$$C_6H_5.CHO + CH_3.CO.CH_3 = C_6H_5.CH:CH.CO.CH_3 + H_2O$$

586. Benzaldoxime, $C_6H_5.CH:NOH$, is of special interest as it exists in two forms. When benzaldehyde is warmed with hydroxylamine an oxime is formed, which melts at 35°:

$$C_6H_5.CHO + H_2NOH = C_6H_5.CH:NOH + H_2O$$

This substance is converted by hydrogen chloride into a salt, which yields an isomer of benzaldoxime when decomposed by sodium carbonate. The isomer melts at 130°, shows the properties of an oxime, and slowly changes into the original oxime when heated. The two substances are considered to be stereoisomers, the relation between the two forms being analogous to that between the *syn*- and *anti*-diazoates:



Syn-aldoxime *Anti*-aldoxime

The two compounds differ in their behavior with acetic anhydride; the one which melts at 130° loses water and passes into benzonitrile, whereas the isomer yields an acetyl derivative which is formed as the result of the replacement of the hydrogen atom of the hydroxyl group by acetyl. The more stable, low-melting compound has been considered to be *anti*-benzaldoxime since it seemed probable that the *syn*-aldoxime, in which the hydrogen atom and hydroxyl group are on the same side of the molecule, would lose water more readily than its isomer. Recent work indicates, however, that the *anti*-form is the one that loses water.

587. Cumic aldehyde (cuminic aldehyde), *iso*-$C_3H_7.C_6H_4CHO(1,4)$ occurs in the oil of caraway and in other essential oils. It is a liquid of characteristic odor, which boils at 235°. It may be isolated from essential oils by treating the latter with sodium hydrogen sulphite, and decomposing the difficultly soluble addition product of the aldehyde and sulphite by distilling it with a solution of sodium carbonate. Aldehydes are usually isolated in this way from the mixtures containing them which occur in nature.

588. Cinnamic aldehyde, $C_6H_5CH{=}CH.CHO$, occurs in oil of cinnamon, oil of cassia, and other essential oils. It may be isolated from these sources through the preparation of its addition product with sodium hydrogen sulphite. It is prepared by condensing benzaldehyde with acetaldehyde in the presence of a dilute solution of sodium hydroxide:

$$C_6H_5.CHO + CH_3.CHO = C_6H_5.CH : CH.CHO + H_2O$$

Cinnamic aldehyde possesses the chemical properties characteristic of aldehydes and of unsaturated compounds. It forms an addition product with bromine, which readily loses hydrogen bromide. It boils at 251°.

Ketones

589. Acetophenone, $C_6H_5.CO.CH_3$.—The aromatic ketones may be prepared by methods which are analogous to those used in the preparation of aliphatic ketones. Acetophenone, for example, is formed when a mixture of calcium benzoate and calcium acetate is distilled:

$$\begin{matrix} C_6H_5.COOca \\ CH_3CO.Oca \end{matrix} = \begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>\!CO + CaCO_3$$

The aromatic ketones are most conveniently prepared by means of the Friedel and Crafts reaction from acyl chlorides and aromatic hydrocarbons:

$$CH_3COCl + C_6H_6 \overset{AlCl_3}{=} CH_3COC_6H_5 + HCl$$

Acetophenone melts at 19.7°, boils at 202.3°, and is slightly soluble in water. It is used in medicine as a hypnotic under the name "hypnone."

The reactions of acetophenone are analogous, in general, to those of the aliphatic ketones. It reacts with hydroxylamine, phenylhydrazine, and hydrocyanic acid, but does not form an addition product with sodium hydrogen sulphite. It is converted into calcium benzoate and chloroform when warmed with a solution of bleaching powder, the reaction being analogous to that between bleaching powder and acetone. Acetophenone is converted by phosphorus pentoxide or hydrogen chloride into triphenylbenzene, the condensation being similar to that in which mesitylene is formed from acetone (**446**). When acetophenone is treated with chlorine or bromine the hydrogen atoms in the methyl radical are replaced by halogen. Chloroacetophenone, $C_6H_5COCH_2Cl$, causes a copious flow of tears; it is used by the police to quell riots.

Acetophenone possesses the properties characteristic of aromatic compounds. When heated with dilute nitric acid it is oxidized to benzoic acid; with concentrated nitric acid nitro derivatives are formed. The chief product of nitration is *m*-nitroacetophenone; a small proportion of the ortho compound is also formed. *p*-Nitroacetophenone can be prepared from *p*-nitrobenzoyl chloride and acetoacetic ester.

590. Benzophenone, $C_6H_5.CO.C_6H_5$, is most conveniently prepared by condensing benzoyl chloride with benzene by means of the Friedel and Crafts reaction. The mechanism of the reaction is clear in this case (see Sec. **438**).

Benzophenone melts at 48.5° and boils without decomposition at 305.4°. When the ketone is formed as the result of the oxidation of diphenylmethane and certain other substances, it is obtained at times in a form which melts at 26.5°. The difference between the two forms is not the result of a difference in structure. The low-melting variety readily passes into the ordinary form when treated with a trace of the latter. The difference in melting point and crystalline structure may be the result of a difference in molecular aggregation. It will be recalled that sulphur, phosphorus, and other elements exist in a variety of forms.

Benzophenone may be reduced to diphenylcarbinol and to diphenylmethane:

$$(C_6H_5)_2CO \longrightarrow (C_6H_5)_2CHOH \longrightarrow (C_6H_5)_2CH_2$$

The carbinol is formed when an alcoholic solution of the ketone is boiled with zinc dust and potassium hydroxide. As in the case of acetone, the ketone is reduced to a secondary alcohol by alkaline reducing agents. When benzophenone is heated to a high temperature with hydriodic acid and red phosphorus it is reduced to the hydrocarbon.

Benzophenone may be nitrated, sulphonated, and chlorinated. When fused with solid potassium hydroxide it is converted into potassium benzoate and benzene. Benzophenone dissolves in concentrated sulphuric acid and is precipitated unchanged when the solution is poured into water. The ketone forms colored addition products with aluminium chloride, ferric chloride, and stannic chloride.

591. Benzophenone forms an addition product with sodium, $(C_6H_5)_2CO.Na$, which is a reactive substance and undergoes condensation. It is assumed that the carbon atom of the carbonyl group becomes trivalent as the result of the addition of the metal to the oxygen atom of this group. Compounds of this type are known as *metallic ketyls*.

592. An important substitution product of benzophenone that is used in the dye stuff industry is the tetramethyldiamino derivative, which is called *Michler's ketone*. It is made by heating dimethylaniline with phosgene in an autoclave:

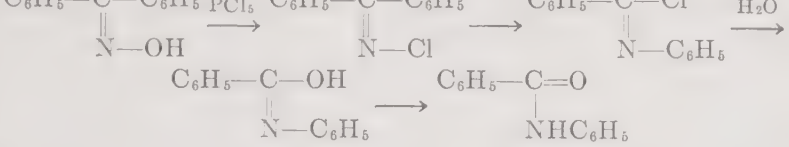
$$COCl_2 + 2C_6H_5N(CH_3)_2 = CO[C_6H_4N(CH_3)_2]_2 + 2HCl$$

The ketone, which contains the dimethylamino groups in the para positions, melts at 174°.

593. Beckmann Rearrangement of Ketoximes.—Ketoximes are the oximes derived from ketones. Benzophenone yields but one oxime, but certain derivatives of benzophenone of the general formula R.CO.R′, in which R and R′ are different radicals, yield oximes which exist in two forms. The isomerism appears to be stereochemical and to result from the fact that the oximes contain a carbon atom linked by a double bond to a nitrogen atom. The formulas of the two oximes of tolyl phenyl ketone are as follows:

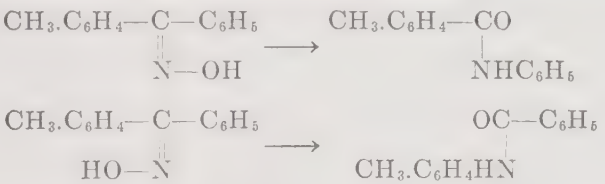
$$CH_3.C_6H_4—C(=N.OH)—C_6H_5 \qquad CH_3.C_6H_4—C(=HO.N)—C_6H_5$$

When ketoximes are treated with phosphorus pentachloride and then with water, they undergo a molecular transformation which is known as the *Beckmann rearrangement*. Benzophenone oxime is converted in this way into benzanilide. The steps involved in the change are probably those indicated below:



The steps involved in the reaction can be readily understood. Phosphorus pentachloride acts normally on the oxime and replaces a hydroxyl group by chlorine. In the resulting compound chlorine is joined to a trivalent nitrogen atom. Compounds which contain these elements in combination are unstable, and as a consequence a molecular rearrangement takes place in which the halogen atom and aryl group change places. The resulting compound on decomposition with water yields the unstable tautomeric form of anilide, which rearranges into the stable form.

By applying the Beckmann rearrangement to stereoisomeric oximes, it is possible to determine the formula which should be assigned to each form of the oxime. The transformations in the case of the two oximes of phenyl-tolyl ketone are indicated by the following formulas:



The first product is the anilide of toluic acid, $CH_3.C_6H_4CO.NHC_6H_5$, and the second the toluide of benzoic acid, $C_6H_5CO.NHC_6H_4.CH_3$. The above formulas are written to indicate a *cis*-rearrangement. Recent work indicates that in the exchange groups in the *trans*-position are involved.

Ketones which contain two very dissimilar radicals, such as acetophenone, $C_6H_5.CO.CH_3$, do not yield isomeric oximes.

594. Benzalacetone, $C_6H_5CH=CH.CO.CH_3$, is an example of an unsaturated aromatic ketone. It is prepared by allowing benzoic aldehyde and acetone to stand in contact with a dilute solution of sodium hydroxide:

$$C_6H_5.CHO + CH_3.CO.CH_3 = C_6H_5.CH:CH.CO.CH_3 + H_2O$$

The condensation is analogous to that by which cinnamic acid is prepared from benzoic aldehyde and sodium acetate, although in the latter case a dehydrating agent is required to bring about

the elimination of water. Benzalacetone melts at 42°, and possesses the properties of an unsaturated compound and of a ketone.

When acetone is treated with two molecules of benzaldehyde, dibenzalacetone, which crystallizes in yellow plates (m.p. 112°), is formed:

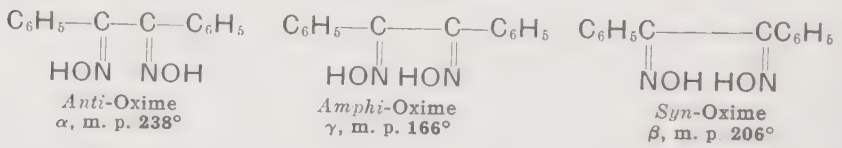
$$2C_6H_5.CHO + (CH_3)_2CO = (C_6H_5CH:CH)_2CO + 2H_2O$$

595. Benzil, $C_6H_5.CO.CO.C_6H_5$, is an aromatic diketone. It is most conveniently prepared by oxidizing benzoin (**603**) with nitric acid:

$$C_6H_5.CHOH.CO.C_6H_5 + O = C_6H_5.CO.CO.C_6H_5 + H_2O$$

Benzil crystallizes from alcohol in yellow needles which melt at 95.2°. It takes part in many reactions which are characteristic of ketones. It may be reduced to desoxybenzoin, $C_6H_5.CH_2.CO.C_6H_5$, to benzoin, $C_6H_5.CHOH.CO.C_6H_5$, and to hydrobenzoin, $C_6H_5.CHOH.CHOH.C_6H_5$.

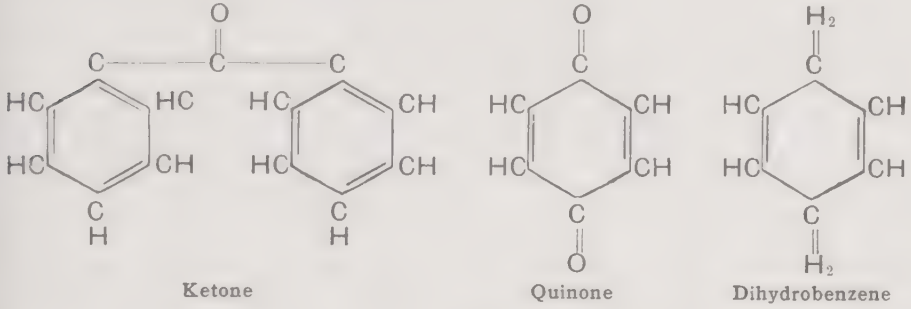
The dioxime of benzil exists in the three stereoisomeric forms represented by the following formulas:



Quinones

596. It has been repeatedly pointed out that the chemical properties of substitution products of aromatic hydrocarbons which contain a substituent in the side chain, are markedly different from those of isomeric compounds in which the substituent is linked to a carbon atom of the ring. The fact is especially noticeable in the case of compounds which contain the carbonyl, C=O, group. In the ketones so far considered, the oxygen atom is joined by two bonds to a carbon atom which is outside of the ring. Compounds are known in which an oxygen atom is joined by two bonds to a carbon atom of the ring; those which contain two such carbonyl groups are called quinones; they differ markedly in properties from ordinary ketones. The rela-

tion between the structures of a ketone, a quinone, and dihydrobenzene is shown by the following formulas:



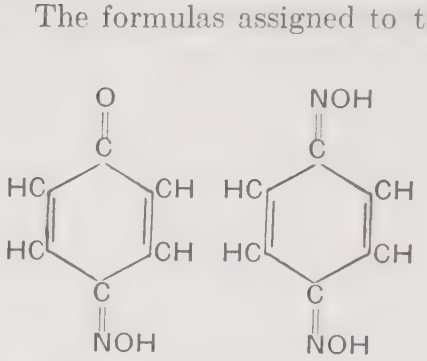
A carbon atom in a benzene ring can hold in combination but one atom of a univalent element, as three of its bonds are involved in the ring formation peculiar to benzene. In order to form a compound in which one of the carbon atoms of the nucleus is joined by two bonds to a bivalent element, it is necessary to bring into play the latent affinities of the carbon atoms. As a consequence, the peculiar neutralization of the fourth bonds of the atoms of the ring, which is characteristic of benzene, is destroyed; and the resulting compound is a derivative of dihydrobenzene. In the quinones derived from benzene the two carbonyl groups may be either ortho or para to each other. The quinone which has been fully studied is the para compound.

597. Quinone, $C_6H_4O_2$, is also called benzoquinone to indicate that it is the quinone related to benzene. It crystallizes in yellow needles, which melt at 115.7°, has a peculiar, pungent odor, and is volatile with steam with partial decomposition.

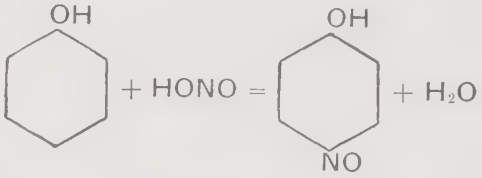
Quinone is obtained by the partial oxidation of many para derivatives of benzene, such as hydroquinone, $C_6H_4(OH)_2$; *p*-aminophenol, $NH_2.C_6H_4.OH$; sulphanilic acid, $NH_2.C_6H_4.SO_3H$; and *p*-phenolsulphonic acid, $HO.C_6H_4.SO_3H$. It is prepared by oxidizing aniline with an aqueous solution of potassium dicromate and sulphuric acid.

Quinone reacts with hydroxylamine and forms a monoxime and a dioxime. This fact indicates that it contains two carbonyl groups which possess the properties of the carbonyl

group in ketones. The formulas assigned to the oximes are as follows:

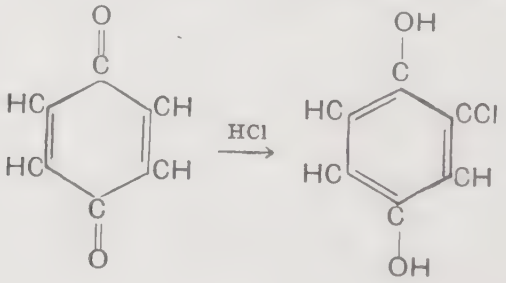


The monoxime is also formed by the action of nitrous acid on phenol; its preparation in this way indicates that the compound is nitrosophenol:



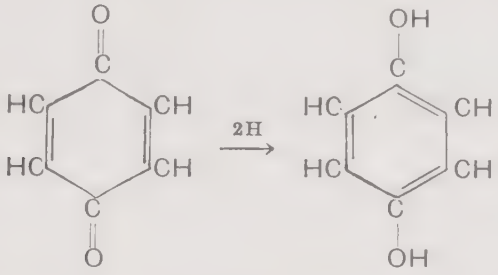
Some of the reactions of the compound lead to the view that it is an oxime, and others to the view that it is a phenol. With an excess of hydroxylamine it is converted into the dioxime—a fact in favor of the oxime formula; when oxidized in alkaline solution by potassium ferricyanide, *p*-nitrophenol is formed—a fact which is best explained on the assumption that the compound is *p*-nitrosophenol.

Quinone possesses the properties of an unsaturated compound; it unites with two or with four atoms of bromine when treated in chloroform solution with the halogen. This fact is in accord with the view that quinone is a derivative of dihydrobenzene, which is a highly unsaturated compound. It also unites with hydrogen chloride; the compound formed is chlorohydroquinone:



When quinone is treated with chlorine, substitution takes place and tetrachloroquinone, also called chloranil, is formed. When it is oxidized by potassium persulphate in the presence of silver sulphate and sulphuric acid it is converted into maleic acid—a fact in accord with the structure which has been assigned to quinone.

Quinone is reduced in cold aqueous solution to hydroquinone by sulphurous acid, hydriodic acid, and other reducing agents:



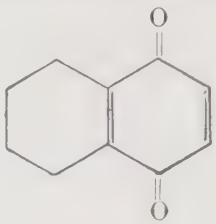
Quinone forms with a number of compounds addition products, the structures of which have not been established. *p*-Nitroaniline, for example, yields a compound of the formula $C_6H_4O_2.C_6H_4(NO_2)NH_2$, which forms red crystals. The addition product with hydroquinone, called *quinhydrone*, $C_6H_4O_2.C_6H_4(OH)_2$, is of interest as it is an intermediate product formed in the oxidation of hydroquinone to quinone by ferric chloride and other oxidizing agents. Quinhydrone forms brownish-red prisms with a green metallic luster.

The quinones are colored substances. It is thought that the color is the result of the peculiar molecular structure which these compounds possess. The constitution of many colored substances is best explained by the hypothesis that they contain the so-called "quinonoid" configuration. The relation between color and structure is discussed in the chapter on dyes.

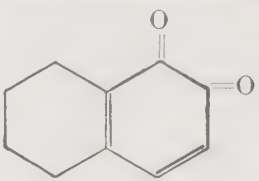
o-Benzoquinone has been prepared by oxidizing *o*-dihydroxybenzene with silver oxide. *m*-Dihydroxybenzene does not yield a simple quinone.

598. 1,4 or α-Naphthoquinone, $C_{10}H_6O_2$, is formed by the oxidation of many α-derivatives of naphthalene. It is most conveniently prepared by oxidizing a solution of naphthalene in acetic acid with chromic acid. α-Naphthoquinone has a pungent odor, sublimes readily, and crystallizes in yellow needles which melt at 125°. It resembles, in general, benzoquinone in chemical

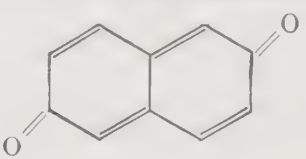
properties but it is not so readily reduced. As it is reduced to 1,4-dihydroxynaphthalene, and is converted into phthalic acid on oxidation, its structure is that represented by the following formula:



1,2 or β-**Naphthoquinone,** $C_{10}H_6O_2$, (m.p. 120°), is formed by oxidizing 1,2-dihydroxynaphthalene; its structure is that represented by the formula:



2,6 or *amphi*-**Naphthoquinone,** $C_{10}H_6O_2$ (m.p. 135°) is formed when 2,6-dihydroxynaphthalene in benzene solution is oxidized with lead oxide. It has a red color and is odorless. It resembles benzoquinone closely in chemical properties; it is reduced by dilute solutions of hydriodic acid and by sulphurous acid. Its structure is best represented by the following formula:



The distribution of the fourth valences of the carbon atoms in the α- and β-naphthoquinones is uncertain as in the case of naphthalene. It is probable, however, that in both the α- and β-compounds there is one ring like those in naphthalene; in the case of the amphi compound, both rings have been converted into the configuration present in dihydrobenzene. It is clear why the amphi compound more closely resembles benzoquinone in chemical properties than its isomers.

599. Anthraquinone, $C_{14}H_8O_2$, is obtained by oxidizing anthracene with chromic acid or nitric acid:

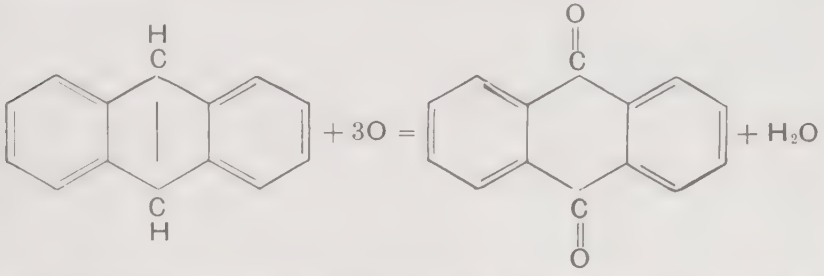
$$C_6H_4(CH)_2C_6H_4 + 3O = C_6H_4(CO)_2C_6H_4 + H_2O$$

It can be prepared on a large scale by passing air and the vapor of anthracene over vanadium oxide at about 450°.

Anthraquinone crystallizes from hot benzene in yellow prisms or needles, which melt at 285°, boil at 379.8°, and can be sub-

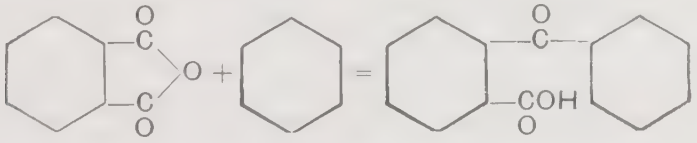
limed. It does not show the properties characteristic of quinones and is, therefore, not well named. It is not easily reduced, is not readily volatile, and does not possess a pungent odor.

It has been pointed out that the behavior of quinones is best explained on the view that they are derivatives of dihydrobenzene; and that the ease with which they are reduced and add halogen atoms is the result of the highly unsaturated nature of the reduced benzene ring. The conversion of anthracene into anthraquinone does not involve the change of a benzene ring into a dihydrobenzene ring. Assuming that anthracene has the structure which has been assigned to it, the oxidation of the hydrocarbon to anthraquinone is best represented by the following formulas:



In the conversion of anthracene into anthraquinone, the para bond between the two carbon atoms involved in the oxidation is broken, but no change takes place in the benzene rings present in the compound.

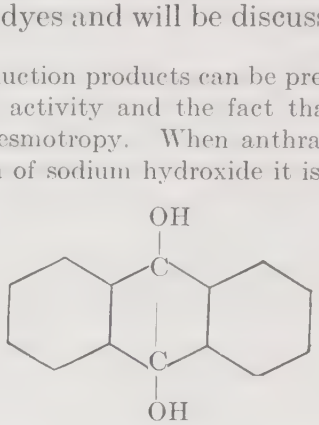
The synthesis of anthraquinone from phthalic anhydride confirms this view of its structure. When the anhydride is treated with benzene and aluminium chloride, a product is formed which yields, after acidification, *o*-benzoylbenzoic acid:



Concentrated sulphuric acid converts the latter into anthraquinone. This method of synthesis is used in the United States for manufacturing anthraquinone and a number of its derivatives that are important intermediates in the preparation of certain classes of dyes (**671**) Anthraquinone can be converted into

nitro derivatives, halogen substitution products, and sulphonic acids. Many derivatives of anthraquinone are known, some of which are important dyes and will be discussed later (**654**).

600. Intermediate reduction products can be prepared which are of interest on account of their activity and the fact that some of them exhibit an interesting case of desmotropy. When anthraquinone is warmed with zinc dust and a solution of sodium hydroxide it is reduced to *anthraquinol*:



The two hydroxyl groups possess acidic properties and in the presence of the alkali the disodium salt, which has a blood-red color, is formed. In aqueous solution the salt is oxidized by air to anthraquinone, and as the latter is insoluble in water, the solution becomes colorless. The reaction is used in testing for anthraquinone.

Problems

1. Summarize in the form of equations (*a*) the methods of preparation, and (*b*) the reactions of aromatic aldehydes. (*c*) Indicate in what reactions they differ from aliphatic aldehydes.

2. Write equations for reactions by which the following may be prepared from benzaldehyde: (*a*) $C_6H_5CH_2OH$; (*b*) C_6H_5COOH; (*c*) *m*-$NO_2C_6H_4CHO$; (*d*) $C_6H_5CHOHCH_3$; (*e*) $C_6H_5CH{=}CHCH_3$; (*f*) $C_6H_5CH{=}CHCOOH$; (*g*) $C_6H_5CH{=}CHCH_2OH$; (*h*) C_6H_5CN; (*i*) $C_6H_5CHOHCOOH$.

3. Indicate by equations how the following may be prepared: (*a*) $ClCH_2COC_6H_5$; (*b*) *p*-$ClC_6H_4COCH_3$; (*c*) *m*-$ClC_6H_4COCH_3$; (*d*) *p*-$ClC_6H_4CH{=}CHCOCH_3$; (*e*) *p*-$CH_3C_6H_4COC_6H_5$; (*f*) *o*-$BrC_6H_4COC_6H_5$.

4. Write the structural formulas of the compounds formed in applying the Beckmann rearrangement to $C_6H_5COC_6H_4Cl$.

5. By what chemical tests could you distinguish the following: (*a*) $(C_6H_{13})_2CO$ and $(C_6H_5)_2CO$; (*b*) $C_6H_5COCH_2Br$ and $BrC_6H_4COCH_3$; (*c*) C_3H_7CHO and C_6H_5CHO; (*d*) $NH_2C_6H_4CHO$ and $NO_2C_6H_4CHO$; (*e*) *p*-$C_6H_4(OH)_2$ and *m*-$C_6H_4(OH)_2$; (*f*) $C_6H_5C_6H_3O_2$ (phenyl-*o*-benzoquinone) and $C_6H_4(CO)_2C_6H_4$?

6. State what occurs when each of the following is treated with (I) cold concentrated H_2SO_4; (II) hot concentrated HNO_3; (III) Cl_2; (IV) a hot solution of NaOH: (*a*) CH_3CHO; (*b*) C_6H_5CHO; (*c*) CH_3COCH_3; (*d*) $C_6H_5COCH_3$; (*e*) $CH_3COOC_6H_5$; (*f*) $C_6H_5COOCH_3$; (*g*) CH_3CH_2OH; (*h*) $C_6H_5CH_2OH$.

CHAPTER XXVI

AROMATIC COMPOUNDS CONTAINING TWO OR MORE UNLIKE GROUPS

601. Many thousand derivatives of aromatic hydrocarbons containing two or more unlike groups have been prepared. A few compounds of this class have already been described. Only certain typical examples will be discussed here, and those considered will be selected in such a way as to illustrate the methods of preparation and properties of such compounds. The general statement which has been given in regard to the effect of a group in a compound on the position taken by an entering group (**466**) should be reviewed at this point, as it will be seen that the conclusions summarized in this statement serve as a most valuable guide in devising methods to prepare a compound of a given structure.

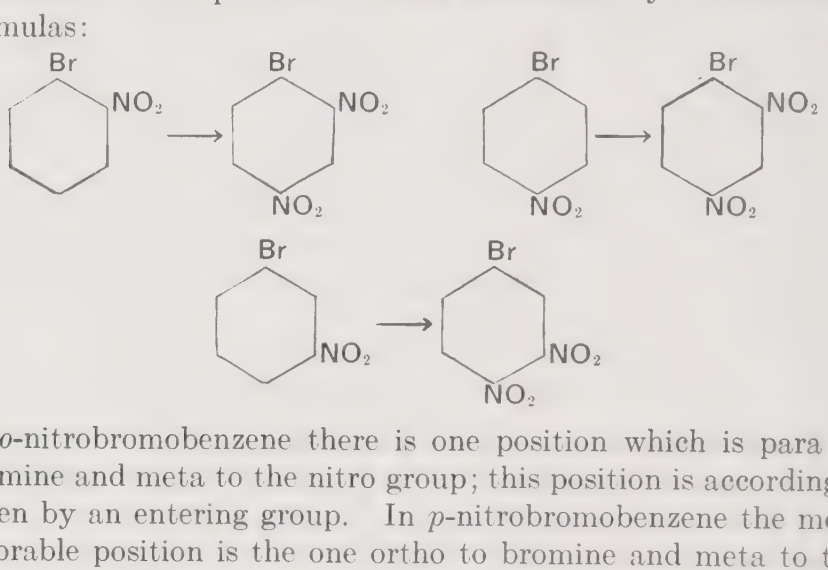
Nitrohalogen Derivatives

602. Nitrobromobenzenes, $Br.C_6H_4.NO_2$.—Three compounds of this formula exist. When bromobenzene is nitrated, the bromine atom sends the nitro group to the para and ortho positions, the chief product of the reaction being *p*-nitrobromobenzene (m.p. 127°). On the other hand, when nitrobenzene is brominated, the nitro group sends the halogen atom to the meta position, and an excellent yield of *m*-nitrobromobenzene (m.p. 56°) is formed.

The chemical properties of the three isomers illustrate the effect of the relative position of substituents on their reactivity. *o*-Nitrobromobenzene (m.p. 43°) is converted into *o*-nitroaniline when heated at 190° with an alcoholic solution of ammonia, and into *o*-bromophenol when heated at a high temperature with water and potassium hydroxide. In one reaction the halogen atom is removed by ammonia, and in the other the nitro group by potassium hydroxide. *p*-Nitrobromobenzene enters into

similar reactions, but the meta compound is not affected by the same reagents under the same conditions. In general, the effect of a substituent on the reactivity of an atom or group decreases as we pass from the ortho to the para to the meta compound, the effect of the group in the meta position being much less than that of one in the other positions. The reactions of the three dinitrobenzenes, which have been described in Sec. **473,** furnish an interesting example of this principle.

The compounds formed by nitrating the isomeric nitrobromobenzenes furnish an illustration of the principle in regard to the orienting effect of substituents on entering groups. The structures of the products formed are shown by the following formulas:



In *o*-nitrobromobenzene there is one position which is para to bromine and meta to the nitro group; this position is accordingly taken by an entering group. In *p*-nitrobromobenzene the most favorable position is the one ortho to bromine and meta to the nitro group. There is no position in *m*-nitrobromobenzene to which both bromine and the nitro group tend to send a substituent, and as a consequence a mixture of compounds is obtained, among which the substance of the structure given above is present in the largest amount. In the formation of this compound the directing influence of the bromine atom predominates, and the substituent takes its place para to the halogen, although this place is ortho to a nitro group.

Ketone Alcohols

603. Benzoin, $C_6H_5.CO.CHOH.C_6H_5$ (m.p. 133°), is an example of a ketone alcohol (ketol). The method by which it is prepared

from benzoic aldehyde has been given in Sec. **582.** The oxygen atom and hydroxyl group, which give to benzoin its characteristic properties, are linked to carbon atoms not situated in a ring. As a consequence, benzoin resembles the analogous aliphatic compounds in many of its properties. Benzoin is an α-hydroxyketone as it contains the group —CO.CHOH—. It will be recalled that certain sugars, the ketoses, contain this group; like these, benzoin reduces Fehling's solution and forms a phenylhydrazone and an osazone.

Benzoin is oxidized by nitric acid to benzil, $C_6H_5.CO.CO.C_6H_5$. It is reduced by zinc and hydrochloric acid in alcoholic solution to desoxybenzoin, $C_6H_5.CO.CH_2.C_6H_5$; by sodium amalgam to hydrobenzoin, $C_6H_5.CHOH.CHOH.C_6H_5$; and by hydriodic acid to bibenzyl, $C_6H_5.CH_2.CH_2.C_6H_5$.

Derivatives of Phenols

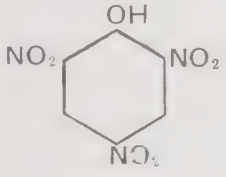
604. Nitrophenols, $NO_2.C_6H_4.OH$.—*o*-Nitrophenol (m.p. 45°) and *p*-nitrophenol (m.p. 113°) are formed by the nitration of phenol. As the presence of the hydroxyl group facilitates markedly the introduction of substituents, the nitration is effected by dilute nitric acid at a low temperature. When reaction is complete the product is washed with water and distilled with steam, with which the ortho compound is volatile.

o-Nitrophenol has a yellow color and possesses a characteristic odor; its isomers are colorless and odorless, but yield highly colored salts.

m-Nitrophenol (m.p. 96°) is prepared from *m*-nitroaniline by the diazo reaction. Many meta compounds are prepared from the dinitro derivatives which result from direct nitration.

The nitrophenols are more acidic than phenols, as they decompose hot solutions of sodium carbonate. They are precipitated, however, from their solutions in alkalies by carbon dioxide.

605. Picric acid (trinitrophenol), $(NO_2)_3.C_6H_2.OH$, has the symmetrical structure:



It is formed as the result of the action of concentrated nitri acid on a large number of substances, such as certain protein resins, and many aromatic compounds. Picric acid is prepare by adding concentrated nitric acid to a solution of phenol i concentrated sulphuric acid, and finally heating the mixtur at 100°. It can be prepared by the action of nitric acid on ben zene in the presence of mercury nitrate, which acts as a catalyti agent; the benzene is oxidized and nitrated during the course o the reaction which takes place.

Picric acid melts at 121.8° and crystallizes from water in light yellow leaflets, and from ether in prisms; it has a bitter taste, i poisonous, and decomposes with explosion when heated rapidly Aqueous solutions of picric acid have a distinctly yellow color they dye silk and wool.

Picric acid exhibits acidic properties; it decomposes car bonates, and forms well-characterized salts. The effect of the nitro groups in increasing the negative nature of the phenyl radical is clearly seen in picric acid and its derivatives. Trinitro chlorobenzene reacts with water and with ammonia according to the following equations:

$$(NO_2)_3C_6H_2.Cl + HOH = (NO_2)_3C_6H_2.OH + HCl$$

$$(NO_2)_3C_6H_2.Cl + HNH_2 = (NO_2)_3C_6H_2.NH_2 + HCl$$

The analogy between the trinitrophenyl radical and acyl radicals is seen by comparing the properties of trinitroaniline and of acid amides. The amine may be prepared from the chloride according to the reaction expressed by the above equation, which is analogous to that made use of in the preparation of amides, or by the action of ammonia on the ethers of picric acid:

$$(NO_2)_3C_6H_2OCH_3 + NH_3 = (NO_2)_3C_6H_2NH_2 + CH_3OH$$

The method of preparation last given is similar to that by which amides are prepared from esters. Trinitroaniline, which is called *picramide*, reacts as an amide when heated with alkalies:

$$(NO_2)_3C_6H_2.NH_2 + KOH = (NO_2)_2C_6H_2.OK + NH_3$$

All the reactions which have been given bring out the important fact that a carboxyl group is not essential to an organic acid. Picric acid is a stronger acid than acetic acid, although the latter contains a carboxyl group and the former does not.

Picric acid forms with a number of aromatic hydrocarbons molecular compounds which crystallize well, can be readily purified, and possess definite melting points. Such compounds are frequently prepared in the isolation of hydrocarbons and in their identification. The molecular compounds are decomposed into their constituents when treated with ammonia.

606. Nitro Compounds as Explosives.—Nitro compounds prepared from aromatic hydrocarbons and certain of their derivatives were very important explosives used in the World War. The compounds differ markedly in the properties which are characteristic of explosives, namely: (1) sensitiveness to shock, (2) explosive force, and (3) the velocity of the explosion through the substance. If (1) is very high the explosive cannot be transported very safely; (2) determines the amount of the explosive to be used; if (3) is very high, the pressure is developed to its maximum so suddenly that rupture of the gun in which it is used may take place. Substances which are very sensitive to shock are used as detonators or boosters; a small amount of the material is exploded by the trigger and the explosive wave set up causes the explosion of the less sensitive material. Mercury fulminate, lead azide, $Pb(N_3)_2$, and several nitro derivatives of aniline (see below) are used for this purpose.

The explosive force of the nitro derivatives of benzene and its homologues increases with the number of nitro groups and decreases with the number of methyl radicals. Symmetrical trinitrobenzene is a very powerful explosive but on account of the difficulty of introducing three nitro groups into the benzene ring it has been little used. Toluene can be nitrated more readily and the symmetrical trinitro derivative (**474**) was extensively used in the World War; it is called *TNT.* or, in Europe, *trotyl* or *tolite.* The trinitro derivative of metaxylene, $C_6H(CH_3)_2$1,3,$(NO_2)_3$ 2,4,6, which was also used is a powerful explosive. Picric acid and trinitrometacresol, $C_6H(OH)$1, (CH_3)3,$(NO_2)_3$ 2,4,6, are also explosives of great power. The higher nitro derivatives of aniline and methylaniline are very sensitive to shock and are valuable boosters. Tetranitroaniline, $C_6H(NH_2)$1,$(NO_2)_4$ 2,3,4,6, is prepared by nitrating metanitroaniline; it is called *TNA. Tetryl* is a tetranitro derivative of methylaniline which has the structure $\begin{matrix}CH_3\\ \diagdown\\ \quad N—C_6H_2\\ \diagup\\ NO_2\end{matrix}$ $(NO_2)_3$ 2,4,6; the presence of the nitro group joined to nitrogen makes it especially sensitive to shock. *Hexite* or *hexil* is the symmetrical hexanitro derivative of diphenylamine, $HN\begin{matrix}\diagup C_6H_2(NO_2)_3,\ 2,4,6\\ \diagdown C_6H_2(NO_2)_3,\ 2,4,6\end{matrix}$; it was the high explosive used in bombs which were dropped on London.

Various mixtures of explosives are used either to decrease cost or to obtain the explosive force desired. The most important of these is *amatol* which

contains TNT. and ammonium nitrate; the proportions used varied from 20:40 of the former, to 80:60 of the latter. Tetryl was used as the booster in shell filled with amatol. *Cresylite* is a mixture of 60 parts of picric acid and 40 parts of trinitrometacresol.

A very powerful explosive called *analite*, which was used in drop bombs, consisted of gasoline and nitrogen tetroxide. The two substances were automatically brought into contact as the bomb fell through the air, and when the impact fired the detonator a very powerful explosion resulted.

607. Bromophenols, $Br.C_6H_4.OH$.—The presence of the hydroxyl group in phenol makes the replacement of hydrogen atoms by halogen take place so readily that special precautions have to be taken in order to replace but one hydrogen atom. When a current of air which contains bromine vapor is passed into phenol, a mixture of *o*-bromophenol (b.p. 195°) and *p*-bromophenol (m.p. 63.5°) is formed. The compounds are best prepared from the corresponding bromoanilines by the diazo reaction. This reaction is used in preparing *m*-bromophenol (m.p. 33°), as a halogen atom does not enter the ring meta to a hydroxyl group, if there is a hydrogen atom in the ring ortho or para to this group.

When an aqueous solution of phenol is treated with bromine water, symmetrical tribromophenol (m.p. 96°) is formed; in the presence of an excess of bromine water an unstable compound of the formula $Br_3C_6H_2.OBr$ is precipitated.

608. Phenolsulphonic Acids, $HO.C_6H_4.SO_3H$.—When phenol is treated in the cold with concentrated sulphuric acid, the chief product of the reaction is the ortho acid. In many cases a low temperature favors the formation of ortho compounds. When the sulphonation is effected by warming phenol with sulphuric acid, the para compound is formed. The ortho acid rearranges into the para acid when it is boiled with water.

m-Phenolsulphonic acid is prepared by the cautious fusion of *m*-benzenedisulphonic acid with potassium hydroxide; with an excess of alkali and at a higher temperature, resorcinol is formed.

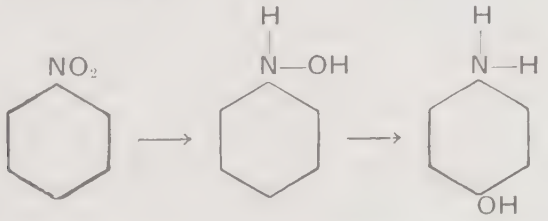
The chemical properties of the phenolsulphonic acids are those of sulphonic acids and phenols. When heated with water and hydrochloric acid under pressure, they are converted into phenol, and when fused with alkalies, dihydroxybenzenes are formed. Like phenols, they react readily with halogens. Bro-

mine water converts *p*-phenolsulphonic acid into mono- and di-substitution products, and finally into tribromophenol.

The mixture of *o*- and *p*-phenolsulphonic acids formed by sulphonating phenol is used as a disinfectant under the name *aseptol*; the sodium salts of the acids are used as a remedy for the form of indigestion which results from a certain kind of fermentation in the stomach.

609. Naphtholsulphonic Acids.—A number of sulphonic acids can be derived from the naphthols. The methods of preparation of one of these, the so-called Neville and Winter's acid, $C_{10}H_6OH(1),SO_3H(4)$, which is used in making dyes, illustrates reactions made use of industrially. The acid can be prepared by diazotizing naphthionic acid, $C_{10}H_6NH_2(1)$, $SO_3H(4)$, in dilute sulphuric acid and heating the solution. It is also made by heating sodium naphthionate with a 50 per cent solution of sodium hydroxide in an autoclave for 10 hours at 200° to 220°. It is most conveniently prepared by heating at 90° a solution of sodium naphthionate and sodium hydrogen sulphite. The ester produced, $C_{10}H_6.OSO_2Na(1),SO_3Na$-(4), is boiled with sodium hydroxide and the salt formed, $C_{10}H_6ONa.SO_3Na$, is converted into the free acid on acidification of the solution.

610. Aminophenols, $NH_2.C_6H_4.OH$.—The three aminophenols may be prepared by reducing the three nitrophenols. *p*-Aminophenol (m.p. 184°) is manufactured by the electrolytic reduction of nitrobenzene dissolved in sulphuric acid. Phenylhydroxylamine is first formed and then undergoes rearrangement in the presence of the strong acid into *p*-aminophenol:



The rearrangement is similar to those which take place in the cases of nitrosomethylaniline and diazoaminobenzene, which have been mentioned (**515, 528**).

The aminophenols possess the properties of amines and of phenols, although the mutual effect of the groups modifies to some extent their activity. The influence of the amino group is seen in the fact that the compounds do not form well-characterized salts with bases, although they are soluble in

alkalies. Like aniline, they form salts with active acids and yield diazo compounds.

The aminophenols are colorless, crystalline solids, which readily turn brown in the air as the result of oxidation. Their salts are more stable.

611. *Photographic Developers.*—The hydrochloride of *p*-aminophenol is used as a photographic developer under the name *rodinal*. A large number of organic compounds which are reducing agents have been used as photographic developers. A study of the structure of the aromatic compounds which give satisfactory results as developers has led to the conclusion that such compounds contain at least two hydroxyl groups, two amino groups, or one hydroxyl and one amino group, in the ortho or para positions to each other. In the case of the amino groups, one of the hydrogen atoms may be replaced by an alkyl radical. In addition to pyrogallol ("pyro") $C_6H_3(OH)_3$ (1,2,3), hydroquinone $C_6H_4(OH)_2$(1,4), pyrocatechol (pyrocatechin) C_6H_4-$(OH)_2$(1,2), and *p*-aminophenol, which have been mentioned, the following named substances are among those which have been used: *amidol*, which is a salt of diaminophenol (OH,1; NH_2,2; NH_2,4); *metol*, the sulphate of methylaminophenol (OH,1; $NHCH_3$,4); and *eikonogen*, which is a sulphonic acid of an aminonaphthol (NH_2,1; OH,2; SO_3H,6).

The oxidation of the compounds used as developers is accelerated in the presence of alkalies and retarded by acids; for this reason most developers are made up just before use from two solutions, one containing the developing agent, and the other sodium carbonate.

Drugs.—A number of derivatives of *p*-aminophenol are used in medicine. The ethyl ether of the phenol, $H_2N.C_6H_4.OC_2H_5$, is known as *paraphenetidine*, from which compounds have been prepared by replacing a hydrogen atom of the amino group by acyl radicals. *Phenacetin*, which is used as an antipyretic, is the acetyl derivative and has the formula $CH_3CO.NH.$-$C_6H_4.OC_2H_5$.

612. Guaiacol, $CH_3O.C_6H_4.OH$(1,2), is so called because it was first obtained from gum guaiacum. It is found among the products of the distillation of wood, and can be prepared from pyrocatechol, of which it is the monomethyl ether. It melts at 28.1° and boils at 205.1°

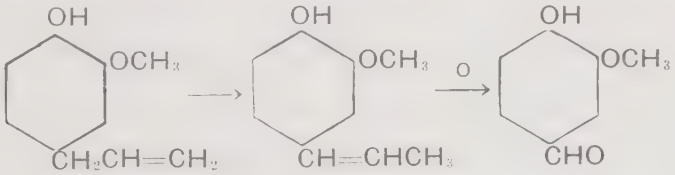
Guaiacol possesses the properties of a phenol and of an ether. It dissolves in alkalies, gives a green coloration with ferric chloride, and is converted into anisole, $C_6H_5OCH_3$, when heated with zinc dust.

613. Eugenol, $C_6H_3(OH)(OCH_3)(CH_2CH{=}CH_2)$(1,2,4), occurs in a number of essential oils. Oil of cloves consists of eugenol and a terpene of the formula $C_{15}H_{24}$. The oil may be obtained

by distilling cloves with steam. Eugenol is a colorless oil with a spicy odor, which boils at 253°. It may be separated from the oil of cloves by treating the latter with an alkali; the phenol dissolves, whereas the hydrocarbon is insoluble. On the addition of acid to the alkaline solution, eugenol is precipitated.

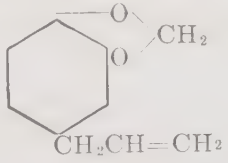
Eugenol possesses the properties of phenols, unsaturated compounds, and ethers. Ferric chloride colors its ammoniacal solution blue, and acetic anhydride converts it into an acetyl derivative. Bromine forms with it dibromoeugenol-dibromide, the substitution being brought about as the result of the presence of the phenolic hydroxyl group, and the addition as the result of the presence of the double bond.

When eugenol is boiled with an alcoholic solution of potassium hydroxide, it is converted into isoeugenol; both compounds yield vanillin on oxidation with potassium permanganate:



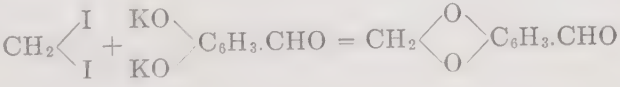
A number of derivatives of eugenol are used as medicinal preparations.

614. Safrole (b.p. 234.5°) is a methylene ether of the structure



It is the chief constituent of the oil of sassafras, and is present in other essential oils. It does not possess phenolic properties. It is converted by alkalies into isosafrole, a change taking place similar to that which eugenol undergoes with the same reagent. Safrole is oxidized in acid solution to acetic aldehyde and piperonal, $CH_2{:}O_2{:}C_6H_3.CHO$, and in alkaline solution to piperonylic acid, $CH_2{:}O_2{:}C_6H_3.COOH$.

Piperonal possesses the odor of heliotrope and is used in perfumery. It may be prepared by treating an alkaline solution of protocatechuic aldehyde with methylene iodide:



Hydroxy Aldehydes

615. Hydroxyl derivatives of aldehydes are usually prepared by what is known as the *Tiemann-Reimer reaction*, which consists in condensing a phenol with chloroform in the presence of an alkali. It is probable that the reaction takes place in steps as indicated by the following equations:

$$KO.C_6H_4.H + Cl.CHCl_2 + KOH = KO.C_6H_4.CHCl_2 + KCl + H_2O$$

$$KO.C_6H_4.CH.Cl_2 + H_2.O = KO.C_6H_4.CHO + 2HCl$$

The condensation is effected by adding chloroform to a warm solution of phenol in an excess of potassium hydroxide. In the first reaction represented above, a hydrogen atom of the benzene ring is replaced by the group $CHCl_2$ as the result of the elimination of hydrochloric acid. The hydrogen atoms which enter into reaction are those in the positions ortho and para to the hydroxyl group. When phenol is used, a mixture of *o*-hydroxy- and *p*-hydroxybenzaldehyde is obtained. As in other cases, the hydroxyl group sends the entering group to the ortho and para positions. The second step in the formation of the aldehyde is similar to the reaction by which benzal chloride is converted into benzaldehyde.

When carbon tetrachloride is used instead of chloroform a similar condensation takes place; the compound formed in this way is a derivative of benzotrichloride and, on hydrolysis, yields a mixture of ortho- and para-hydroxybenzoic acid.

616. Salicylic aldehyde, $HO.C_6H_4.CHO(1,2)$, occurs in the oil of spiræa, which is obtained from the blossoms of the meadow-sweet. It is prepared from phenol by the Tiemann-Reimer reaction. Salicylic aldehyde is a liquid with a pleasant odor, which is volatile with steam and boils at 196.5°. It shows the properties of a phenol and an aldehyde; it gives a violet coloration with ferric chloride, and forms an addition product with potassium hydrogen sulphite, but does not reduce Fehling's solution.

Salicylic aldehyde can be oxidized to *o*-hydroxybenzoic acid and reduced to *o*-hydroxybenzyl alcohol. As a phenol it yields ethers and esters; and as an aldehyde, condensation products.

617. Vanillin, $C_6H_3.OH.OCH_3.CHO$ (1, 2, 4), is the chief constituent of the extract of vanilla, which is obtained by treating vanilla beans with alcohol. It may be prepared from guaiacol by the Tiemann-Reimer reaction. It is made on the large scale by oxidizing isoeugenol—a reaction described above—and from coniferin, a glucoside which occurs in the sap of certain conifers. Coniferin is converted by hydrolysis into glucose and coniferyl alcohol, $C_6H_3(OH)(OCH_3)(C_3H_4OH)(1, 2, 4)$; the latter yields vanillin on oxidation.

Vanillin crystallizes in needles which melt at 81°. It gives a blue coloration with an aqueous solution of ferric chloride, reduces an ammoniacal solution of silver nitrate, and decomposes carbonates. It is oxidized by moist air to vanillic acid, which is formed as the result of the conversion of the aldehyde group into a carboxyl group.

Substitution Products of Amines

618. Sulphanilic acid, $NH_2C_6H_4.SO_3H(1,4)$, *p*-aminobenzenesulphonic acid, is the most important sulphonic acid derived from aniline. It is prepared by heating a mixture of aniline and concentrated sulphuric acid for about 4 hours at 180° to 190°.

Sulphanilic acid is difficultly soluble in cold water, and crystallizes from hot water in crystals which contain two molecules of water and effloresce quickly.

Sulphanilic acid, like other para compounds, is converted by chromic acid into quinone. With nitrous acid it yields a diazo compound, which is used in the preparation of valuable dyes. It forms well-characterized salts with bases, but does not form salts with acids on account of the presence of the strongly negative sulphonic acid group.

The isomers of sulphanilic acid which contain the amino and sulphonic acid groups in the ortho and meta positions, respectively, are prepared by reducing the corresponding nitrobenzenesulphonic acids.

619. Naphthylaminesulphonic Acids.—A large number of isomeric sulphonic acids derived from α- and β-naphthylamine are known and several of them are extensively used in the dye industry.

Naphthionic acid, $C_{10}H_6NH_2(1)SO_3H(4)$, is prepared by heating α-naphthylamine sulphate. When it is heated with an excess of sulphuric acid it is converted into the 1,5 acid which is called *Laurent's acid*. If naphthionic acid is heated with naphthalene it rearranges to the 1,2 acid.

β-Naphthylamine is converted into four monosulphonic acids when heated with sulphuric acid. These are the 2,8; 2,6; 2,5; and 2,7 acids. The 2,6 and 2,7 acids are prepared by heating the corresponding naphtholsulphonic acids with ammonia.

620. Nitroanilines, $NO_2.C_6H_4.NH_2$.—The most readily prepared nitroaniline is that which is formed by partial reduction of *m*-dinitrobenzene. This is accomplished by treating a cold alcoholic solution of the dinitrobenzene with the calculated quantity of a solution of stannous chloride and hydrogen chloride in alcohol:

$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + 3SnCl_2 + 6HCl = C_6H_4\begin{matrix}NO_2\\NH_2\end{matrix} + 3SnCl_4 + 2H_2O$$

The reduction can be effected also by heating the nitro compound with an alcoholic solution of ammonium sulphide:

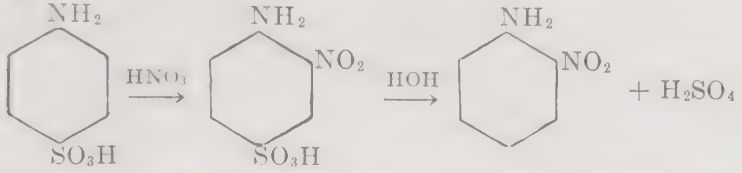
$$C_6H_4\begin{matrix}NO_2\\NO_2\end{matrix} + 3(NH_4)_2S = C_6H_4\begin{matrix}NO_2\\NH_2\end{matrix} + 6NH_3 + 3S + 2H_2O$$

The compound is prepared technically by heating *m*-nitrobenzene with a strong aqueous solution of sodium polysulphide prepared by dissolving sulphur in a solution of sodium sulphide.

621. *o-Nitroaniline* and *p-nitroaniline* are prepared by methods which illustrate the way in which compounds are formed that cannot be made by direct substitution. When aniline is treated with concentrated nitric acid, it is difficult to control the reaction so as to form a mononitro compound. In order to decrease the activity of aniline, the amino group is modified by introducing into it a radical which can be readily removed after substitution has taken place; the acetyl group is commonly employed for this purpose. When acetanilide is nitrated, a mixture of *p*- and *o*-nitroacetanilide is formed, from which the nitroanilines may be obtained by hydrolysis. When a solution of aniline in a large excess of concentrated sulphuric acid is treated with nitric acid, a mixture of *m*- and *p*-nitroaniline is formed.

Orthonitroaniline and *p*-nitroaniline may be obtained in pure condition by methods which are frequently applied in the preparation of other compounds. The ortho compound may be prepared by heating *o*-nitrophenol

with ammonia at 160° for 16 hours, and by the reactions indicated by the following formulas:



The amino group sends an entering group to the para position. In order to prevent the nitro group from taking this position, aniline is first sulphonated. When the resulting compound or its acetyl derivative is nitrated, the nitro group enters the ring ortho to amino and meta to the negative acid group. The nitroaminosulphonic acid is then heated with water and hydrochloric acid under pressure, when the sulphonic acid group is replaced by hydrogen. *p*-Nitroaniline can be made by heating *p*-chloronitrobenzene or *p*-nitrophenol with ammonia under pressure. It is usually prepared by nitrating acetanilide, and saponifying the resulting nitroacetanilide.

The nitroanilines are weak bases; they are difficultly soluble in water, and form salts which are decomposed by water. The ortho, meta, and para compounds melt at 71.5°, 111.8°, and 148° respectively.

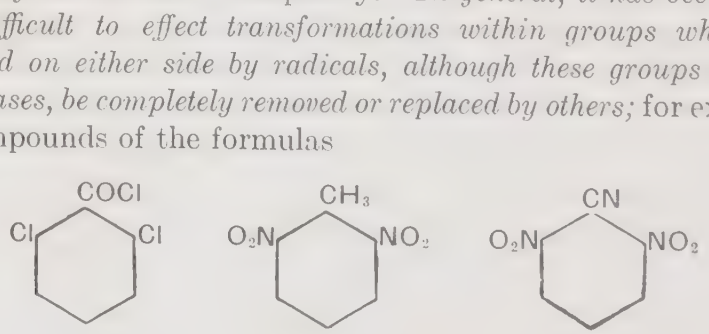
Substitution Products of Acids

622. Nitrobenzoic Acids, $NO_2.C_6H_4.COOH$.—When benzoic acid is heated with concentrated nitric acid, *m*-nitrobenzoic acid is formed. As nitration takes place with difficulty, the acid is usually prepared by treating a mixture of benzoic acid and potassium nitrate with concentrated sulphuric acid. When nitration is effected in this way, the presence of the water contained in concentrated nitric acid is avoided, and a more active nitrating mixture is consequently obtained. The product of the nitration effected in the way just described is a mixture of the meta, ortho, and para acids, in the proportion of about 60, 17, and 2 per cent, respectively, the rest being unaltered benzoic acid. The acids are separated by means of their barium salts, which differ in solubility in water. Isomeric acids are frequently separated by the fractional crystallization of their salts.

o-Nitrobenzoic acid is prepared by oxidizing *o*-nitrotoluene or *o*-nitrocinnamic acid, which is formed by the direct nitration of cinnamic acid. *p-Nitrobenzoic acid* is usually prepared by oxidizing *p*-nitrotoluene or *p*-nitrobenzyl chloride. The ortho, meta, and para acids melt at 147.5°, 141.4°, and 242.4°, respectively; the amides of the acids melt at 176.6°, 142.7°, and 201.4°, respectively.

623. Dinitrobenzoic Acids, $(NO_2)_2.C_6H_3.COOH$.—The most interesting of these acids is the one which contains the two nitro groups in the positions ortho to the carboxyl group. It has been pointed out in the case of picric acid and other compounds that the reactivity of an atom or group is greatly increased by the presence in the compound of substituents in the ortho position to the atom or group. It is possible, for example, to replace readily a chlorine atom situated between two nitro groups by the hydroxyl, methoxyl, amino, and other groups. In the light of these facts the influence on the carboxyl group of two groups in the ortho position to it, is of interest. The carboxyl group can be replaced more or less readily by other groups; for example, 2,6-dinitrobenzoic acid is converted into *m*-dinitrobenzene when heated, and into *m*-diaminobenzene when reduced with tin and hydrochloric acid. When, however, an attempt is made to convert the acid into an ester, the replacement of hydrogen by alkyl takes place with great difficulty.

Most aromatic acids are converted into esters when a solution of the acid in alcohol is saturated with hydrogen chloride. Victor Meyer studied the esterification of many acids in this way and came to the conclusion that acids which contain a carboxyl group placed between two radicals in the ortho position to this group do not yield esters when treated in the way indicated above. This conclusion is known as *Victor Meyer's law of esterification.* Esters of such acids can be prepared, however, by the action of alkyl iodides on the silver salts of the acids; it is a striking fact that they are difficult to saponify. *In general, it has been found very difficult to effect transformations within groups which are protected on either side by radicals, although these groups can, in many cases, be completely removed or replaced by others;* for example, the compounds of the formulas

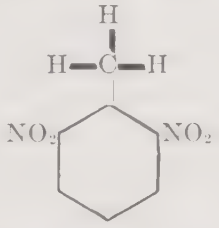


do not exhibit the properties characteristic of substances of the classes to which they belong. The acid chloride can be boiled

for a long time with water without change; the hydrogen atoms in the methyl group of the dinitrotoluene are not replaced by chlorine when the compound is treated with the halogen at 200°; and the nitrile cannot be hydrolyzed to the corresponding acid.

624. Steric Hindrance.—The explanation put forward by Meyer of such facts as these was based on what is called steric hindrance. It was thought that the groups in the ortho position prevented by their presence other molecules from coming into contact with the group between them, and, as a consequence, reaction could not take place. Recent work has shown, however, that the diortho acids form esters normally, but that the rate of the reaction is exceedingly slow.

It is doubtful whether steric hindrance is the cause of the marked inactivity of the compounds which have been mentioned. The hypothesis does not appear to be consistent with the fact that the group itself which is attached to a carbon atom "protected" by substituents in the two ortho positions is unusually reactive chemically and can be readily replaced by other groups. The bond which links an atom with the carbon in the ring is readily broken; on the other hand, any other atom united to such an atom is firmly bound. It is reasonable to suppose that if but a relatively small amount of energy is utilized in establishing one valency of carbon an additional amount is available when the others are established. From this point of view the formula of *o,o*-dinitrotoluene could be written as follows:



It has been repeatedly seen that when a substituent is introduced into a compound the reactivity of the elements present changes. Thus the halogen atom in ethyl bromide, CH_3CH_2Br, is rendered more active when a hydrogen is replaced by a second halogen as in ethylene bromide, CH_2BrCH_2Br. There is no doubt that the replacement affects the energy relation involved in the union of all the elements in the molecule. Up to the present only a roughly qualitative idea of the changes has been reached. A satisfactory method of measuring and expressing these changes quantitatively is one of the most important needs in organic chemistry.

The facts enumerated above show that substituents in the *ortho* position to a side chain have a marked effect on the reactivity of the atoms or groups joined to the first carbon atom in the chain. The facts in regard to the position taken by a substituent when it enters the benzene ring (the rules of orientation, **466**) show that the nature of the atom or group joined to the first

carbon atom of a side chain affects the lability of the hydrogen atoms of the benzene ring and as a consequence the position taken by an entering group.

The two apparently unrelated sets of facts bring out the effect of atoms and groups linked to the ring on the reactivity of those joined to the α carbon atom of the side chain and, conversely, the effect of the latter on the atoms joined to the ring. It will be recalled that when negative atoms are in combination with the α-carbon atom the hydrogen atoms in the *ortho* position are firmly bound, and are not severed when substitution takes place. *meta* derivatives are formed.

625. Sulphobenzoic Acids, $HO_3S.C_6H_4.COOH$.—*m*-Sulphobenzoic acid is obtained by the direct sulphonation of benzoic acid with sulphur trioxide. The ortho and para acids are prepared by oxidizing the corresponding toluenesulphonic acids:

$$C_6H_4\begin{matrix}CH_3\\SO_3H\end{matrix} + 3O = C_6H_4\begin{matrix}COOH\\SO_3H\end{matrix} + H_2O$$

Like phthalic acid, $C_6H_4(COOH)_2$, *o*-sulphobenzoic acid yields an anhydride and an imide:

$$C_6H_4\begin{matrix}CO\\O\\SO_2\end{matrix} \qquad C_6H_4\begin{matrix}CO\\NH\\SO_2\end{matrix}$$

The imide is of particular interest on account of the fact that it possesses a taste which is about 500 times as sweet as that of cane sugar; it is called *saccharin*.

Saccharin can be prepared from toluene by the transformations indicated by the following formulas:

$$C_6H_5CH_3 \longrightarrow C_6H_4\begin{matrix}CH_3\\SO_3H\end{matrix} \longrightarrow C_6H_4\begin{matrix}CH_3\\SO_2Cl\end{matrix} \longrightarrow$$

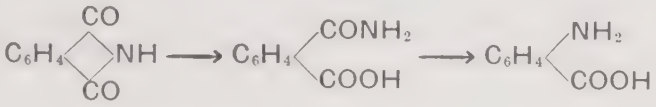
$$C_6H_4\begin{matrix}CH_3\\SO_2NH_2\end{matrix} \longrightarrow C_6H_4\begin{matrix}COOH\\SO_2NH_2\end{matrix} \longrightarrow C_6H_4\begin{matrix}CO\\NH\\SO_2\end{matrix}$$

The product of sulphonation of toluene is a mixture of *p*- and *o*-toluenesulphonic acids. The acids are converted into the sulphonyl chlorides, which may be separated, as the para compound is a solid and the ortho compound is a liquid. The liquid chloride is next converted by ammonia into the amide, which is oxidized in aqueous solution with potassium permanganate. On acidifying the solution saccharin is obtained.

Saccharin (m.p. 228°) is manufactured on a large scale. Its sodium salt is used for sweetening purposes, as a preservative, and as a substitute for sugar by persons suffering from diabetes.

626. Aminobenzoic Acids, $NH_2.C_6H_4.COOH$.—The most important of the aminobenzoic acids is the ortho compound, which is called *anthranilic acid.* It was first obtained from indigo (*anil*).

It is manufactured by treating phthalimide (**575**) with bleaching powder:



The phthalamidic acid first formed as the result of the hydrolysis of the imide is converted directly into the amino acid (Hofmann reaction, **209**).

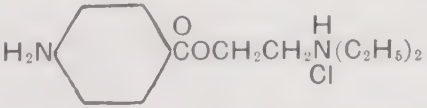
Anthranilic acid melts at 145°, and can be sublimed without decomposition. It possesses a sweet taste, is readily soluble in water, and forms salts with acids and with bases. The methyl ester of anthranilic acid has a pleasant odor, and is used in perfumery.

m-Aminobenzoic acid (m.p. 174°) is prepared by reducing *m*-nitrobenzoic acid. *p-Aminobenzoic acid* (m.p. 187°) is prepared by oxidizing the acetyl derivative of *p*-toluidine, and hydrolyzing the resulting compound:

$$CH_3CO.NH.C_6H_4.CH_3 \longrightarrow CH_3CO.NH.C_6H_4COOH \longrightarrow NH_2.C_6H_4.COOH + CH_3COOH$$

The free amine cannot be converted directly into the acid, as oxidizing agents destroy the amino group; in general, such groups are "protected" when a compound containing them is to be oxidized.

A salt of a substituted ethyl ester of *p*-aminobenzoic acid is the important local anaesthetic called *novocaine;* its formula is



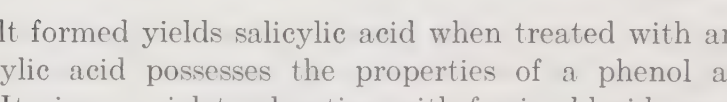
Hydroxy Acids

627. Salicylic acid, $HO.C_6H_4.COOH(1, 2)$, is the most important hydroxybenzoic acid. It derives its name from salicin,

a glucoside obtained from the bark of the willow (*salix*), which yields glucose and *o*-hydroxybenzyl alcohol on hydrolysis.

Salicylic acid occurs in the blossoms of the meadowsweet, in the leaves and stems of tulips and hyacinths, and as the methyl ester in the oil of wintergreen. The acid crystallizes in colorless needles from hot water, melts at 159°, and sublimes at 200° when carefully heated.

Salicylic acid is manufactured by what is known as *Kolbe's synthesis*, which consists in heating the sodium salt of phenol with carbon dioxide under pressure at 140°. The steps involved in the reaction are those indicated below:



The salt formed yields salicylic acid when treated with an acid.

Salicylic acid possesses the properties of a phenol and an acid. It gives a violet coloration with ferric chloride, a precipitate with bromine water ($C_6H_2Br_3.OBr$), and salts with bases. It forms ethers and esters such as those of the formulas

$C_6H_4.OCH_3.COOH$, $C_6H_4.OH.COOCH_3$, and $C_6H_4(O.COCH_3)COOH$. $C_6H_4.OCH_3.COOCH_3$

Salicylic acid is a powerful antiseptic and is used in the preservation of food, wines, and beer; its sodium salt is employed as a remedy in the treatment of rheumatism. Phenyl salicylate, $C_6H_4.OH.COOC_6H_5$, called *salol*, is used in medicine for internal antisepsis; in the intestine it undergoes hydrolysis to phenol and salicylic acid. A great many remedies are derived from salicylic acid: *aspirin*, which is the acetyl derivative of salicylic acid, $C_6H_4(O.COCH_3)COOH$, is commonly used as the soluble sodium salt; *betol* is the β-naphthol ester of the acid.

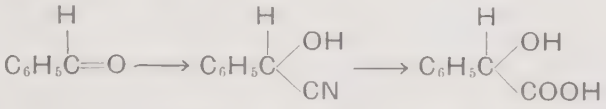
628. ***m*-Hydroxybenzoic acid,** $HO.C_6H_4.COOH(1,3)$, may be prepared from *m*-aminobenzoic acid by the diazo reaction, and by fusing meta compounds, such as *m*-sulphobenzoic acid, *m*-cresol, and *m*-chlorobenzoic acid, with potassium hydroxide. *m*-Hydroxybenzoic acid crystallizes from hot water, and melts at 201°; its solutions are not colored by ferric chloride.

629. ***p*-Hydroxybenzoic acid,** $HO.C_6H_4COOH(1,4)$, is formed in reactions which are analogous to those used to prepare the meta acid. It may be prepared by the action of carbon dioxide on potassium phenolate at 200°. When potassium salicylate is heated at 220°, it is converted into the salt

of *p*-hydroxybenzoic acid of the formula $C_6H_4OK.COOK$; sodium salicylate does not undergo this change.

p-Hydroxybenzoic acid melts at 213°, and at 220° decomposes into phenol and carbon dioxide. With an aqueous solution of the acid, ferric chloride forms a yellow amorphous precipitate; bromine water gives tribromophenol and carbon dioxide.

630. Mandelic Acid, $C_6H_5.CHOH.COOH$.—This compound is an example of acids which contain a hydroxyl group in the side chain. It is made by the general method used to prepare α-hydroxy acids. When benzaldehyde is treated with potassium cyanide and hydrochloric acid, the hydrocyanic acid formed unites with the aldehyde and the resulting nitrile yields mandelic acid on hydrolysis:



Mandelic acid crystallizes from water in rhombic crystals, which melt at 118°. The acid contains an asymmetric carbon atom; the inactive synthetic variety can be converted into dextro- and levo-rotatory acids by crystallizing its cinchonine salt, or by the action of certain bacteria.

When the addition of hydrocyanic acid to benzaldehyde takes place in the presence of quinine, which is levorotatory, the hydroxynitrile formed is optically active and yields on hydrolysis levomandelic acid (m.p. 133°). The same acid is formed when amygdalin (**373**) is hydrolyzed by hydrochloric acid.

The structure assigned to mandelic acid is in accord with its reactions. It is oxidized by an alkaline solution of potassium permanganate in the cold to phenylglyoxylic acid:

$$C_6H_5.CHOH.COOH + O = C_6H_5.CO.COOH + H_2O$$

Fuming hydrobromic acid converts it into α-bromophenylacetic acid, $C_6H_5.CHBr.COOH$, and hydriodic acid and red phosphorus into phenylacetic acid, $C_6H_5.CH_2.COOH$. The acid cannot be nitrated, as concentrated nitric acid oxidizes it to benzaldehyde.

As an alcohol, mandelic acid forms compounds of the type $C_6H_5.CH(OCH_3)COOH$ and $C_6H_5.CH(O.OCCH_3).COOH$ and as an acid those of the type $C_6H_5.CHOH.COOCH_3$. The reactions

of these compounds are what might be expected from the formulas.

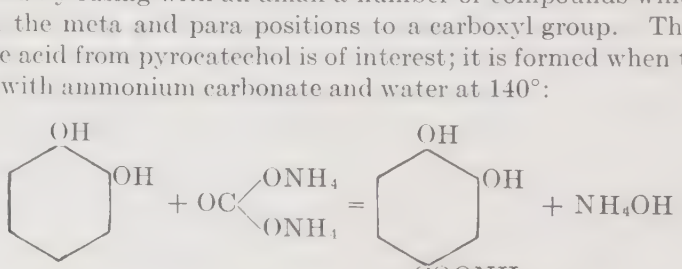
631. Tyrosine, $HO.C_6H_4.CH_2.CHNH_2.COOH$, which α-amino-β-p-hydroxyphenylpropionic acid, is an importan product of the hydrolysis of many proteins. The acid has bee synthesized from β-phenylpropionic acid, $C_6H_5.CH_2.CH_2.COOH$ which can be prepared from benzyl chloride by the use of th malonic ester synthesis. The first steps in the synthesis ar indicated by the following formulas:

$$C_6H_5.CH_2.CH_2.COOH \xrightarrow{HNO_3} NO_2.C_6H_4.CH_2.CH_2.COOH \xrightarrow{Br}$$
$$NO_2C_6H_4.CH_2.CHBr.COOH \xrightarrow{NH_3}$$
$$NO_2.C_6H_4.CH_2.CHNH_2.COOH$$

The nitro group in the acid prepared in this way is replace by a hydroxyl group through the diazo reaction.

Tyrosine has been prepared by a number of interestin methods; one of these involves the condensation of p-hydroxy benzaldehyde and hippuric acid, $C_6H_5CO.NH.CH_2COOH$, b a reaction similar to that which takes place in Perkin's synthesis.

632. Protocatechuic acid, $(HO)_2C_6H_3.COOH(3,4,1)$, is obtained fro many resins when they are fused with potassium hydroxide, and is a produc of the hydrolysis of certain tannins, which will be described later. It ca be prepared by fusing with an alkali a number of compounds which contai groups in the meta and para positions to a carboxyl group. The prepara tion of the acid from pyrocatechol is of interest; it is formed when the phen is heated with ammonium carbonate and water at 140°:



Protocatechuic acid is soluble in water, and melts at 199°. Ferric chloride colors its aqueous solution bluish green, the color changing to blue and finally to red on the addition of alkalies. The acid reduces an ammoniacal solution of silver nitrate, but does not reduce Fehling's solution. It decomposes into pyrocatechol and carbon dioxide when distilled. Bromine in the cold, forms bromoprotocatechuic acid; at 100° the carboxyl group is eliminated and tetrabromopyrocatechol is formed. The monomethyl ether, $C_6H_3(OH)(OCH_3)COOH(4, 3, 1)$, is called *vanillic acid*, as it is formed by the oxidation of vanillin. The dimethyl ether, *veratric acid*, and the methy-

lene ether, $CH_2{:}O_2{:}C_6H_3COOH$, *piperonylic acid*, are obtained from a number of substances which occur in nature.

633. Gallic acid, $C_6H_2(OH)_3COOH(3,4,5,1)$, is the most important trihydroxybenzoic acid. It occurs in gallnuts, sumach, acorns, tea, walnuts, and in the astringent parts of many plants. It is prepared by boiling tannin with dilute acids. The acid crystallizes with one molecule of water, which is given off at 100° to 120°. It does not have a definite melting point; at 215° it begins to decompose into pyrogallol and carbon dioxide. Gallic acid reduces Fehling's solution and the salts of silver and of gold; it gives with ferric chloride a bluish-black precipitate, which dissolves in an excess of the reagent to form a green solution.

634. Tannic Acids.—The name *tannic acid* or *tannin* is applied to a number of vegetable acids which are widely distributed in nature. Tannins occur in the bark of trees and in the leaves and roots of plants. The chief commercial sources of tannin are gallnuts, sumach, oak and hemlock bark, and a number of plants and trees which grow in India and South America. Tannin is used in the tanning of leather and as a mordant in dyeing.

The tannins differ in their reactions with other substances and the products which they yield on hydrolysis, but possess certain properties in common. The tannins are amorphous solids of astringent taste, which are more or less soluble in water and in alcohol, and do not melt or volatilize without decomposition. They give blue-black or green colorations with ferric chloride, and precipitates with lead acetate, copper acetate, and many organic compounds which yield salts with acids. The most characteristic property of tannins is their ability to form with gelatin or gelatin-forming tissues the insoluble compounds which constitute leather.

All tannins are active reducing agents; they reduce Fehling's solution and absorb oxygen from the air—the reaction taking place rapidly in alkaline solutions—and form colored oxidation products.

635. The tannins may be divided into two classes. To one belong the tannins which give a blue-black coloration with ferric chloride, and yield gallic acid on hydrolysis and pyrogallol when decomposed by heat; the tannins of the second class give green solutions with ferric chloride and yield

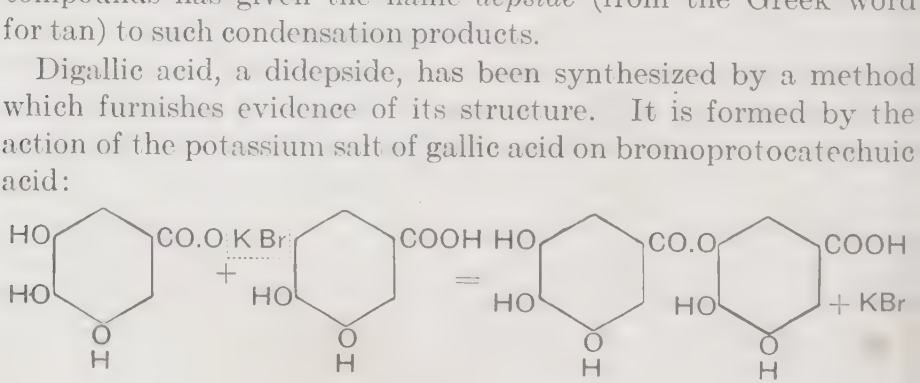
pyrocatechol when heated. The tannins of the first class are converted by fusion with caustic alkalies into gallic acid or ellagic acid, which is derived from the tannin by loss of water; the tannins of the second class yield under the same conditions protocatechuic acid, together with phloroglucinol and acetic acid or other fatty acid. These facts lead to the view that one class of tannins is derived from gallic acid, and the other is derived from protocatechuic acid.

636. Gallotannic acid (tannin) usually occurs as a glucoside or in combination with other carbohydrates in gallnuts, which contain about 70 per cent of the acid. Galls or gallnuts is the name given to the excrescences on various kinds of trees which are formed as the result of the puncture of the bark by insects.

Gallotannic acid separated from gallnuts by extraction with alcohol, ether, and water is obtained as a colorless amorphous mass or light-yellow scales. It is soluble in 6 parts of cold water and is precipitated by dilute hydrochloric acid or sodium chloride. It is removed from its solutions by skin or other gelatinous material. At 215° it begins to decompose, and pyrogallol and carbon dioxide are formed. Gallotannic acid reduces the salts of silver, gold, mercury, and copper, and precipitates many alkaloids and proteins from their solutions.

A study of the freezing points of solutions of the tannins has yielded results that lead to the conclusion that they all possess very high molecular weights—a fact in accord with their colloidal properties. Since the number of compounds formed as the result of their hydrolysis is relatively small, it is probable that they are the result of the condensation—with the loss of the elements of water—of hydroxybenzoic acids, such as gallic acid and protocatechuic acid. Emil Fischer who studied this class of compounds has given the name *depside* (from the Greek word for tan) to such condensation products.

Digallic acid, a didepside, has been synthesized by a method which furnishes evidence of its structure. It is formed by the action of the potassium salt of gallic acid on bromoprotocatechuic acid:



The synthesis indicates that digallic acid is an ester derived from two molecules of gallic acid as the result of the interaction of the carboxyl group of one molecule with a hydroxyl group of the other. A synthesis of digallic acid from gallic acid confirms this view; it is formed when anhydrous gallic acid is heated with phosphorus oxychloride at 120°.

The formula assigned to digallic acid is in accord with its reactions. The acid is converted into gallic acid by hydrolysis, forms a penta-acetyl derivative when heated with acetic anhydride, and is converted into the amide and the ammonium salt of gallic acid when boiled with a solution of ammonia.

Some tannins yield glucose on hydrolysis. It is highly probable that such compounds are esters formed from carbohydrates and depsides. Fischer synthesized the pentadigalloyl ester of glucose by treating the carbohydrate with the chloride of digallic acid. It resembled closely the tannin from gallnuts. The compound has the formula $C_{76}H_{52}O_{46}$; it is of interest on account of the fact that although its molecule is so complex its structure is known.

637. The tannin from gallnuts is used in making *writing inks*. One variety of inks is made from an extract of galls to which a gum, ferrous sulphate, a trace of sulphuric acid, and a blue dye are added. The acid prevents the oxidation of the ferrous sulphate and thus renders the ink stable; the dye gives a color to the solution so that the writing made with it can be seen. When the ink is placed on paper the alumina in the latter neutralizes the acid, and the ferric salt formed as the result of action of the air, reacts with the tannin and a black compound is produced.

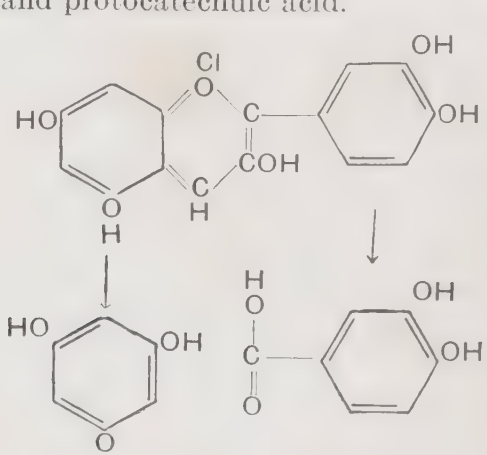
Iron inks of this type may be removed from paper or fabrics by treating them with oxalic acid. The coloring matter of the ink—ferric gallotannate—is reduced by the acid to a ferrous salt, which is colorless and soluble in water.

Some writing inks are made from organic dyes. Many of these cannot be decolorized by oxalic acid, as the reducing agent is not active enough to convert them into colorless compounds. Such inks are often destroyed when they are treated with solutions of sodium hypochlorite and hydrochloric acid.

Indelible inks consist of finely divided carbon held in suspension by gluten, an alkaline solution of shellac, or similar medium; they frequently contain indigo. Colored inks are usually solutions of coal tar dyes to which gum arabic has been added in order to make the ink flow smoothly from the pen, and to prevent its spreading when put upon paper. Marking inks usually consist of a solution of the nitrate or other salt of silver to which some colored substance is added.

638. Caffetannic acid (caffetannin), $C_{15}H_{18}O_9$, is an exampl of a tannin derived from protocatechuic acid. It occurs i coffee berries. When fused with potassium hydroxide, it yield protocatechuic acid and acetic acid, and when heated alone i gives pyrocatechol. It is not affected by a solution of gelatin It does, however, form an insoluble compound with a protei present in milk. It is for this reason that the bitter taste of tea which is caused by the caffetannic acid extracted from the leaves is reduced when milk is added.

639. The Coloring Matter of Flowers.—The study of the colored substances present in flowers has shown that these compounds are glucosides, and that they all contain a nucleus made up of two benzene rings joined by a third ring of which oxygen is a member. The name *cyanins* has been given to this group of compounds. When the cyanin of the cornflower is hydrolyzed it yields glucose and cyanidin chloride, which has been shown to have the structure given below. The proof of the structure rests in part on the fact that from the compound can be obtained phloroglucinol and protocatechuic acid.

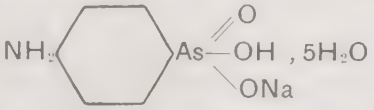


Phloroglucinol Protocatechuic acid

The coloring matters of other flowers resemble closely in structure the compound present in the cornflower; that of the scarlet pelargonium differs only in having but one hydroxyl group (para) joined to the benzene ring indicated at the right in the above formula. In the case of the larkspur there are three hydroxyl groups in this ring (two meta and one para). The

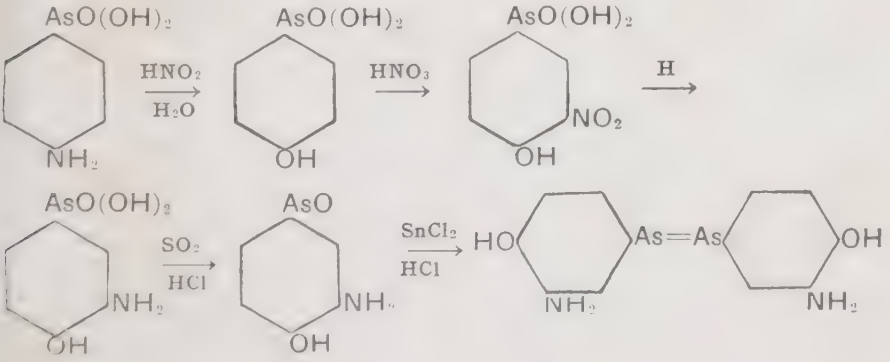
same compound is found in the violet in combination with the sugar rhamnose.

640. Aromatic Arsenic and Mercury Derivatives.—Aromatic compounds containing arsenic and others containing mercury have been recently investigated exhaustively on account of the fact that they have proved to be valuable in destroying the organisms that bring about certain diseases. The arsenic derivatives are related either to *atoxyl*, which is the sodium salt of *p*-aminobenzenearsonic acid



or to arsenobenzene, which resembles azobenzene in structure, $C_6H_5As{=}AsC_6H_5$.

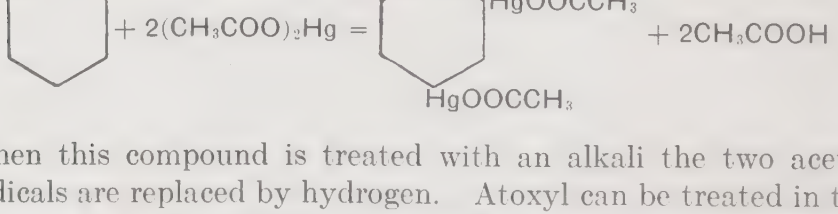
The acid of which atoxyl is the sodium salt is made by heating aniline with arsenic acid at 170° to 200° for several hours. The reaction is similar to that in which sulphanilic acid is formed from aniline and sulphuric acid, and for this reason the product is sometimes called *arsanilic acid*. Atoxyl was first used in cases of anaemia, sleeping sickness, syphilis, malaria, sarcoma, and other diseases. It was found to be a cumulative poison and when repeated doses were given it proved to be toxic to both the pathogenic protozoa and to the host of the organism. The search for a substance, the curative dose of which was small compared with the dose toxic to man, resulted in the discovery of the substance first called "606" because it was the 606th substance investigated; it is now called *arsphenamine* or *salvarsan*. The compound can be prepared through the use of the transformations indicated by the following formulas:



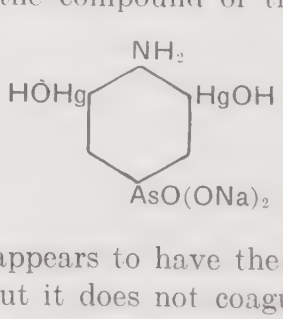
Arsphenamine is the hydrochloride of this compound; it contains two molecules of the acid and crystallizes with two molecules of water.

A large number of derivatives of arsphenamine have been made and some of them are used because the ratio between the curative dose and the toxic dose is more favorable than the case of the simpler substance. Neosalvarsan (Ehrlich's 914) is extensively used; it is the derivative made by replacing one hydrogen in one amino group by the group $—CH_2OSONa$. The compounds are efficacious in combating the diseases due to *Spirillaceae*. They are used in cases of malaria, plague, leprosy, pernicious anaemia, and syphilis. They have been used with success in certain diseases contracted by horses, such as pleuropneumonia, African glanders, and anthrax. The drug is administered by intravenous injection.

641. On account of the fact that a mixture of salvarsan and mercury salts proved more efficient than the former, attempts were made to obtain compounds that contained both arsenic and mercury. This was accomplished by making use of a reaction which had been formerly employed to join mercury to a benzene ring. When aniline is boiled with an aqueous solution of mercuric acetate, condensation takes place:



When this compound is treated with an alkali the two acetyl radicals are replaced by hydrogen. Atoxyl can be treated in the same way and yields the compound of the following formula:



Mercury in this form appears to have the desired effect on the pathogenic protozoa, but it does not coagulate proteins, and is

therefore better adapted to the purpose to which it is put than the inorganic compounds of the element.

Ionization Constants of Aromatic Acids

642. The nature of the substituents in an aromatic acid, and their position relative to the carboxyl group, have a marked effect upon the extent to which the acids are ionized in aqueous solution. A number of examples have been given of the effect of one group on the activity of another, and it has been pointed out that the positions of the groups with respect to each other are an important factor in bringing about the difference in activity of isomeric compounds. The effect of a substituent on the activity of an acid, and the effect of the same substituent on the reactivity of compounds containing groups other than the carboxyl group, may be traceable in part to the same cause, namely, the effect of the substituent in modifying the nature of the radical in combination with the carboxyl or other groups present. One of the cases cited of the influence of groups on one another is that of the dinitrobenzenes (**473**). One of the nitro groups of the ortho compound can be removed readily by certain reagents, whereas *m*-dinitrobenzene is not affected under the same conditions. In the light of this fact it is of interest to compare the effect of a nitro group in the ortho position and one in the meta position on the reactivity of a carboxyl group. The ionization constant of *o*-nitrobenzoic acid is 0.00616, and that of *m*-nitrobenzoic acid is 0.00035; an *o*-nitrophenyl radical is much more effective in increasing reactivity than a *m*-nitrophenyl radical. We should expect, therefore, a compound which contains the former to react with water more readily than one which contains the latter radical.

The conclusion as to the effect of a radical drawn from a consideration of the ionization constant of the acid containing it, is a valuable guide in interpreting the chemical behavior of compounds which consist of the radical in combination with some atom or group. There appear to be, however, other factors, but little understood, which affect the influence of groups on one another, and as a consequence the conclusions arrived at in regard to the properties of certain compounds as the result of the study of the ionization constants of acids, are not always strictly

in accord with the facts. Ionization is quite a different kind of transformation from that involved in the usual type of reaction between organic molecules. It is probable, therefore, that the effect of substituents is different in the two types of reactions. The subject is one that demands further study.

The ionization constants of a few aromatic acids are given below. The student will find it of interest to study the figures in connection with properties of the aromatic compounds which have been described, in the way exemplified above in the case of the dinitrobenzenes.

The effect of the relation of the position of a substituent to that of the carboxyl group is shown by the following constants:

IONIZATION CONSTANTS

Acid	$100K^{25°}$	Acid	$100K^{25°}$
$C_6H_5.COOH$	0.00586	$NO_2C_6H_4.COOH(o)$	0.614
$ClC_6H_4COOH(o)$	0.128	$NO_2C_6H_4.COOH(m)$	0.0316
$ClC_6H_4.COOH(m)$	0.0152	$NO_2C_6H_4.COOH(p)$	0.0388
$ClC_6H_4.COOH(p)$	0.0091	$CH_3C_6H_4COOH(o)$	0.0117
$BrC_6H_4.COOH(o)$	0.142	$CH_3C_6H_4.COOH(m)$	0.00505
$BrC_6H_4.COOH(m)$	0.0135	$CH_3C_6H_4.COOH(p)$	0.0038
$HOC_6H_4.COOH(o)$	0.100	$C_6H_5CH_2.COOH$	0.00545
$HOC_6H_4.COOH(m)$	0.00854	$C_6H_5CH_2.CH_2COOH$	0.00223
$HOC_6H_4.COOH(p)$	0.0028	$C_6H_5CH=CH.COOH$	0.00351

A substituent in the position ortho to the carboxyl group has a marked effect on the ionization of the acid; the constant of *o*-nitrobenzoic acid is 100 times that of benzoic acid.

The relation between the constant of the para acid and that of the ortho or meta acid varies with the nature of the substituent. While *p*-nitrobenzoic acid is a slightly stronger acid than *m*-nitrobenzoic acid, the constant of *p*-chlorobenzoic acid is only about one-half that of the meta acid. The case of *p*-hydroxybenzoic acid is a striking one; while *o*-hydroxybenzoic acid and *m*-hydroxybenzoic acid are more highly ionized than benzoic acid, the constant of the para acid is less than half that of benzoic acid. A satisfactory explanation of such facts as these would, no doubt, materially advance organic chemistry. The effect of a phenyl

radical on a carboxyl group in a side chain is shown by the constants for phenylacetic acid, hydrocinnamic acid, and cinnamic acid.

The constants for a few of the acids which have been described in this chapter are given below. The carboxyl group in each case is numbered 1:

Acid	$100K^{25°}$	Acid	$100K^{25°}$
$NH_2.C_6H_3SO_3H(2, 1)$.....	0.325	$(HO)_2.C_6H_3.COOH(2, 6, 1)$.	5.00
$NH_2.C_6H_3SO_3H(4, 1)$.....	0.057	$(HO)_3.C_6H_2.COOH(3,4,5,1)$	0.0038
$(HO)_2.C_6H_3.COOH(2,3,1)$	0.112	$C_6H_4.(COOH)_2(2, 1)$.....	0.117
$(HO)_2.C_6H_3.COOH(3,4,1)$	0.0031	$C_6H_4.(COOH)_2(3, 1)$	0.028

Problems

1. Indicate the procedures to be used to prepare the *ortho*-, *meta*-, and *para*-chloro derivatives of the following: (*a*) C_6H_5OH; (*b*) C_6H_5COOH; (*c*) $C_6H_5NO_2$; (*d*) $C_6H_5OCH_3$; (*e*) $C_6H_5NH_2$.

2. By what reactions could the following transformations be effected: (*a*) *m*-$NH_2C_6H_4Cl$ into *m*-HOC_6H_4Cl; (*b*) *p*-$NO_2C_6H_4CH_3$ into *p*-$CH_3OC_6H_4CH_3$; (*c*) *p*-$NH_2C_6H_4OH$ into *p*-$ClC_6H_4OCH_3$; (*d*) *o*-$NO_2C_6H_4C_2H_5$ into *o*-$NH_2C_6H_4COOCH_3$; (*e*) $C_6H_5CH_3$ into *sym*.-$C_6H_3(NO_2)_3$; (*f*) *p*-$NH_2C_6H_4OH$ into *p*-$CH_3OC_6H_4COOH$?

3. Write equations for the reactions involved in the preparation of tyrosine from *p*-hydroxybenzaldehyde and hippuric acid.

4. Write the graphic formulas of the mono- and di-bromo substitution products formed by the action of bromine or *ortho*-, *meta*-, and *para*-aminobenzoic acid.

5. By what chemical tests could you distinguish the following: (*a*) *m*-$ClC_6H_4NO_2$ and $ClC_6H_2(NO_2)_3$ (1, 2, 4, 6); (*b*) guaiacol from eugenol; (*c*) aspirin from salicylic acid; (*d*) mandelic acid from benzoic acid; (*e*) picric acid from *p*-nitrophenol; (*f*) benzoin from benzil; (*g*) phenolsulphonic acid from phenylsulphuric acid; (*h*) salicylic aldehyde from vanillin; (*i*) salol from betol?

6. From a consideration of the ionization constants of organic acids, what would you expect to happen if (*a*) *o*-nitrobenzoic acid and (*b*) *p*-hydroxybenzoic acid were added separately to a solution of sodium benzoate?

7. Write graphic formulas for the compounds that gave the following results: (*a*) The compound C_8H_9Cl was converted by oxidation into *m*-chlorobenzoic acid. (*b*) The compound C_8H_9Cl was converted by mild oxidation into *p*-toluic acid. (*c*) The compound C_8H_8O was converted by oxidation into benzoic acid. (*d*) The compound C_8H_8O was converted by oxidation into toluic acid.

CHAPTER XXVII

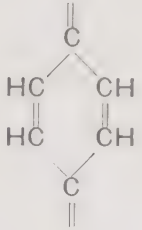
DYES

643. Dyes are compounds which can be used to color cotton, wool, linen, silk, leather, and other substances. In order to be of value as a dye the colored compound must unite with the substance to be dyed in such a way that the resulting product is not materially affected by the treatment to which it is subjected in use, such as rubbing or washing with soap and water. Dyes which are not appreciably affected by exposure to sunlight are said to be "fast" to light; those which fade rapidly are called "fugitive."

A study of the chemical composition of dyes and other colored compounds has led to certain important conclusions among which are the following:

When white light falls upon a substance more or less of it is absorbed. If the absorption of the vibrations is greater in one part of the visible spectrum than in the rest, the light that is reflected or transmitted is colored. Many substances, for example benzene, absorb the ultraviolet radiations, but as these do not produce the sensation of color such compounds are not considered colored, although the phenomena in the two cases are similar. A study of the relationship between color and the structure of organic molecules from this point of view has brought out the fact that a state of unsaturation is an important factor involved. In general, this must exist in two or more places in the molecule, the positions of which must bear a definite relation to each other. A double bond followed by a single bond and then a double bond,—C=C—C=C—(a conjugated system), appears to be favorable to light absorption. Every colored compound contains such a grouping of atoms called a "chromophore" group, to which the production of color can be attributed. Examples of such groups are the nitro, NO_2, and azo,

—N=N—, groups when joined to the benzene ring, and the quinonoid group:



It is thought that the absorption and, consequently, the color is produced as the result of the vibrations set up in the electrons present in the atoms; the alternate single and double bonds appear to be favorable to a transfer to and fro of the electrons from one atom to another. The weight of the molecule is an important factor in determining what radiations are absorbed, and as a consequence the color of the compound.

The introduction into a colored compound of atoms or groups which do not of themselves produce color, such as bromine and alkyl groups, has a marked effect on the color. In general, an increase in molecular weight of a colored compound in this way is associated with a deepening of the shade, or a change in color which takes place ordinarily in the order yellow, orange, red, violet, blue, green, black.

Many colored compounds cannot be used as dyes on account of the fact that the color which they impart to wool or silk is readily removed by washing with water. In most cases, however, such compounds can be converted into dyes by introducing into them acidic or basic groups. Azobenzene, $C_6H_5N{=}NC_6H_5$, for example, is a bright-red compound, but does not possess the properties of a dye. The amino derivative of azobenzene, however, is a dye which is known as aniline yellow.

Some of the groups which impart to colored compounds the property of forming stable combinations with fabrics and thus convert them into dyes, have a marked effect in intensifying the color of the dye, while others have little effect. To the first class, which are called "auxochrome" groups, belong the hydroxyl, amino, and substituted amino groups. The sulphonic acid and carboxyl groups have little if any effect on the color of a compound into which they are introduced. Many dyes are

converted into sulphonic acids, however, in order to render them more soluble in water.

The nature of the union between a dye and a fabric is still an open question. It is probable that in certain cases chemical compounds are formed, and that in others the fabric forms with the dye a solid solution, or holds it mechanically within its fibers as the result of absorption. The fact that many colored substances which contain weakly acidic or basic groups dye wool and silk but do not dye cotton is evidence that the fixing of the dye in the animal fiber is probably the result of chemical action. Wool and silk are proteins and cotton is a carbohydrate. The proteins form compounds with weak acids and bases, whereas cotton, which is cellulose, reacts only with the strongest acids and bases. Cotton can be dyed by some organic compounds, however—a fact which leads to the view that in certain cases the union of the dye and the fabric is of a physical nature.

Dyes may be classified according to their constitution, such as azo dyes, phthaleins, alizarins, etc., but from the standpoint of the dyer the more important classification is that which is based on the behavior of the dyes with fibers. Dyes are grouped in this way as *substantive* or *direct*, and *adjective* or *mordant*. Dyes are also classed as *acid* and *basic;* the former are salts of color acids and are usually applied in acid solution; the latter are salts of color bases. In addition to the dyes belonging to these classes, there are a few, such as indigo and other "vat" dyes, aniline black, and the so-called "ingrain colors," which are produced by chemical reactions within the fiber.

The commercial names given to dyes do not as a rule indicate their structure or the compounds from which they are prepared. Different manufacturers give different names to the same dye. The letters appended to the commercial names of dyestuffs may be indicative of the shade, R referring to red (*rot*), G to yellow (*gelb*), and B to blue (*blau*); 2R, 3R, etc., indicate a deeper shade than that represented by R. At times other letters are used, which refer to the private nomenclature of manufacturers.

644. Substantive Dyes.—The dyes of this class are absorbed from solution by the fiber, and combine with it in such a way that the fiber is dyed by simply immersing it in the solution of the dye. With certain coloring matters dyeing is effected more

readily in a weakly acidic solution, and with others in a weakly alkaline solution. Acid sodium sulphate, acetic acid, and tartaric acid are often added to the dye bath. Silk is usually dyed in a weak soap solution, or in a bath containing sodium phosphate. Salts are frequently added to the bath to reduce the solubility of the dye and to obtain faster or more even colors; sodium sulphate, sodium chloride, and magnesium sulphate are used for this purpose.

The animal fibers combine with most of the organic dyes. Cotton and other vegetable fibers cannot, in general, be dyed directly with the organic coloring matters except with certain so-called sulphur colors or with dyes derived from benzidine. Mercerized cotton, cellulose nitrates, and cellulose acetates can be dyed by substances which do not affect unaltered cellulose.

645. Adjective Dyes, Mordants.—The dyes classed as adjective are those which do not form stable combinations with fibers and, as a consequence, when they are used, the material to be dyed must be treated first with some substance with which the dye combines. Such substances are called *mordants*. The combination between the dye and the mordant may be physical or chemical. Finely divided substances, such as silica, sulphur, and calcium phosphate, adsorb dyes readily, and serve as useful mordants in certain cases. Albumen is used in calico printing, as it unites with substantive dyes directly. When cotton cloth which has been printed with a mixture of the dye and albumen is steamed, the protein is coagulated and the color becomes fixed.

The more widely applicable mordants are inorganic basic salts which form compounds with acidic dyes. When cotton is treated with aluminium acetate and subjected to the action of steam, the salt undergoes hydrolysis and basic acetates are formed. Cloth treated in this way can be dyed directly, as the basic salts form insoluble compounds with dyes. In mordanting cloth to be dyed with basic colors, a compound is used which is an acid or yields an acid on hydrolysis. Tannic acid, soap, and the so-called "pink salt," $SnCl_4.2NH_4Cl$, are examples of this class of mordants.

646. Ingrain Colors.—Dyes of this class are deposited on the fabric as the result of the formation of the color by a chemical reaction which takes place in the dye bath. This may be accom-

plished by treating the cloth to be dyed with one of the material from which the color is to be prepared and then placing it in a bath of the second material. The dye is then formed within the fiber of the cloth and is firmly held. Examples of this kind of dyeing are mentioned under para red (**651**) and primuline (**673**). In dyeing with indigo (**707**) the soluble colorless compound deposited on the cloth is converted by exposure to the oxygen of the air to a colored insoluble blue dye.

647. Dye Intermediates.—The compounds used in making dyes are classed as intermediates. Among these are many compounds which have already been described, such as aniline, dimethylaniline, benzidine, the nitroanilines, phenol, naphthols, anthraquinone, etc. The formulas of the more important intermediates derived from naphthalene are given below to indicate the great variety of compounds which have been utilized. It would lead too far to describe how chemists have been able to prepare and isolate each of the large number of compounds used. The conditions which affect the formation of isomeric compounds have been fully studied, and methods of preparation are used which cannot be treated in an elementary book. The preparation of dye intermediates is one of the great triumphs of organic chemistry.

648. The following sulphonic acids derived from β-naphthol are used: *Schaffer's acid*, $C_{10}H_6OH(2),SO_3H(6)$; *Baeyer's acid*, $C_{10}H_6OH(2),SO_3H(8)$; *R acid*, $C_{10}H_5OH(2),(SO_3H)_2(3,6)$; and *G acid*, $C_{10}H_5OH(2),(SO_3H)_2(6,8)$. The R and G acids are so called because they yield, respectively, red and yellow (*gelb*) dyes. *Neville and Winther's acid* is a derivative of α-naphthol, $C_{10}H_6OH(1),SO_3H(4)$; and *naphthionic acid* of α-naphthylamine, $C_{10}H_6NH_2(1),SO_3H(4)$. *H acid* is an aminonaphtholdisulphonic acid, $C_{10}H_4NH_2(1),OH(8),(SO_3H)_2(3,6)$; the monosulphonic acid, $C_{10}H_5NH_2(1),OH(2),SO_3H(4)$, is also used.

649. Nitro Dyes.—Many of the nitro derivatives of phenols possess marked colors, and are useful as dyes. Among these are *picric acid* (trinitrophenol); *Martius yellow*, which is a salt of dinitro-α-naphthol, $OH(1),(NO_2)_2(2,4)$; and *naphthol yellow S* or *brilliant yellow*, which is a sulphonic acid derivative of Martius yellow, $OH(1),(NO_2)_2(2,4),SO_3H(7)$.

Azo Dyes

650. The dyes of this class are derived from aromatic azo compounds, such as azobenzene, $C_6H_5—N=N—C_6H_5$. They

are prepared by treating a diazonium salt with an amine or a phenol. Thus, if a solution of *m*-phenylenediamine is added to a dilute solution of benzenediazonium chloride, the hydrochloride of diamino-azobenzene, which is the dye *chrysoidine*, is formed:

$$C_6H_5.N_2.Cl + C_6H_4(NH_2)_2 = C_6H_5.N_2.C_6H_3(NH_2)_2.HCl$$

Similar condensations between diazonium salts and alkaline solutions of phenols yield hydroxyazo compounds:

$$C_6H_5.N_2.NO_3 + C_6H_5ONa = C_6H_5.N_2.C_6H_4OH + NaNO_3$$

A great variety of dyes may be prepared by reactions analogous to those just given. It is possible to diazotize any primary aromatic amine and condense the resulting diazonium salt with amines and phenols. The condensation takes place readily only in the case where the diazo group replaces a hydrogen atom in the position para to the amino, substituted amino, or hydroxyl group. The dyes prepared in this way range in color from yellow to orange, red-brown, violet, and black.

651. Aniline yellow (*p*-aminoazobenzene hydrochloride) $C_6H_5.N_2.C_6H_4NH_2.HCl$, is the simplest azo dye (**529**). As the color is fugitive it is not now used as a dye. It forms, however, the starting point in the preparation of other dyes, as it can be diazotized and "coupled" with amines or phenols.

Methyl orange, $NaO_3S.C_6H_4.N_2C_6H_4N(CH_3)_2$, belongs to the class of *tropaeolins* which are yellow or orange sulphonated azo dyes. Methyl orange (helianthine) is the sodium salt of the azo compound formed by condensing with dimethylaniline the diazo compound derived from sulphanilic acid. Silk and wool are dyed a bright-orange color when immersed in an acid solution of helianthine. The free sulphonic acid is a valuable indicator in titrating acids and bases.

652. Butter yellow, $C_6H_5.N_2.C_6H_4N(CH_3)_2$, is the dimethyl derivative of *p*-aminoazobenzene. It is chiefly used for coloring butter and oils.

Orange II is an example of an azo dye prepared from a hydroxyl derivative. It is made by condensing the diazo derivative made from sulphanilic acid with β-naphthol; it is a salt of the acid of the formula $HO_3SC_6H_4N_2C_{10}H_6OH$.

Para red is usually dyed by passing the fabric which has been treated with β-naphthol and dried through an ice-cold solution of the diazo compound prepared from *p*-nitroaniline. Dyes which are applied in this way are

often called ice colors. Para red is very stable and is used in the manufacture of certain varieties of bright-red paint.

Bismarck brown is a mixture of the hydrochlorides of the compounds formed by the action of nitrous acid on *m*-phenylenediamine. A part of the amine is converted into a diazonium salt, which immediately condenses with more of the amine to form an azo compound. The two formulas given below have been assigned to the substances prepared in this way:

$$H_2N.C_6H_4.N_2.C_6H_3(NH_2)_2 \quad \text{and} \quad C_6H_4\begin{<}{N_2.C_6H_3(NH_2)_2}{N_2.C_6H_3(NH_2)_2}$$

Bismarck brown is much used for dyeing leather. The dye is formed when *m*-phenylenediamine is treated in aqueous solution with a trace of nitrous acid; it thus serves as a test for nitrites in water analysis.

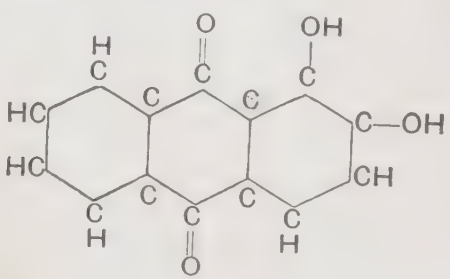
653. Congo red is a tetrazo dye derived from benzidine. It is prepared by condensing the diazo compound from this amine with naphthionic acid, $C_{10}H_6NH_2.SO_3H(1, 4)$, and has the following formula:

$$\begin{array}{l} C_6H_4.N_2.C_{10}H_5.NH_2.SO_3Na \\ | \\ C_6H_4.N_2.C_{10}H_5.NH_2.SO_3Na \end{array}$$

A solution of congo red is blue in the presence of acids and red in the presence of bases. The dye colors cotton a bright crimson-red, but the color is not permanent; wool is dyed a bright scarlet.

Hydroxy-ketone Dyes

654. Alizarin, $C_6H_4(CO)_2C_6H_2(OH)_2$, the most important member of the hydroxy-ketone dyes, is the dihydroxyanthraquinone of the structure



Alizarin occurs as a glucoside, ruberythric acid, $C_{26}H_{28}O_{14}$, in madder root, from which the dye was formerly obtained. It is now manufactured from anthracene. The preparation of the dye involves the oxidation of anthracene to anthraquinone, the sulphonation of the latter, and the fusion of the resulting anthraquinone-monosulphonic acid with sodium hydroxide. Potas-

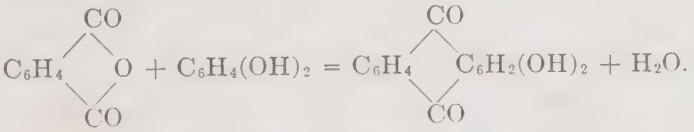
sium nitrate or potassium chlorate is added to the mixture to be fused in order to prevent the reduction of the alizarin by the hydrogen formed during the reaction, which takes place according to the equation:

$$C_6H_4(CO)_2C_6H_3SO_3Na + 3NaOH = C_6H_4(CO)_2C_6H_2(ONa)_2 + Na_2SO_3 + H_2O + H_2$$

When the product of the fusion is acidified, alizarin is precipitated.

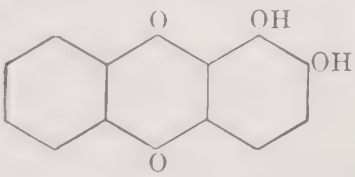
Alizarin crystallizes from alcohol in reddish-yellow prisms which melt at 290° and sublimes at a higher temperature in orange needles. Solutions of the sodium salt of alizarin give colored precipitates called "lakes" with solutions of the salts of most metals. The precipitates with barium and calcium salts are purple, and those with aluminium and tin are red; ferrous salts yield violet, and ferric salts black-violet, precipitates. The color of a fabric dyed with alizarin is thus determined by the metallic salt used as the mordant. Turkey red, for example, is produced by a series of operations involving the use of aluminium salts and an oil which furnishes fatty acids.

655. Alizarin is reduced to anthracene when heated with zinc dust—a transformation which was the first step taken in determining the structure of the dye contained in madder root. The view that alizarin is a dihydroxyl derivative of anthraquinone follows from the fact that it is formed as the result of the fusion of anthraquinonesulphonic acid with caustic alkalies, and from the synthesis of the dye by heating phthalic anhydride and pyrocatechol with sulphuric acid at 150°:

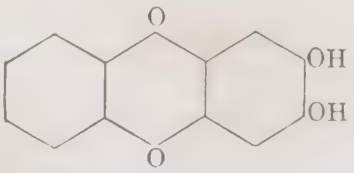


The formation of alizarin from pyrocatechol indicates that the hydroxyl groups are in the ortho position, and that the structure of the dye should be represented by either of the following formulas:

(I)



(II)



A study of the products which result from the nitration of alizarin shows that formula (I) is correct. In the two mononitro derivatives formed, the

nitro group is in combination with the ring to which the hydroxyl groups are joined, since the two derivatives yield phthalic acid on oxidation. As a compound of the structure represented by formula (II) could not yield two such mononitro derivatives, the conclusion is drawn that the structure of alizarin is that indicated by formula (I).

656. A number of derivatives of alizarin are used as dyes. Among these are *alizarin red S*, which is the sodium salt of the monosulphonic acid derived from alizarin, and *alizarin orange*, which is nitroalizarin. *Anthragallol*, the essential constituent of anthracene brown, has the structure $C_6H_4(CO)_2C_6H(OH)_3$ (1, 2, 3). *Purpurin*, which occurs with alizarin in old madder root, and can be prepared by oxidizing alizarin with manganese dioxide and sulphuric acid, is an isomer of anthragallol in which the hydroxyl groups are in the positions 1, 2, 4.

Triphenylmethane Dyes

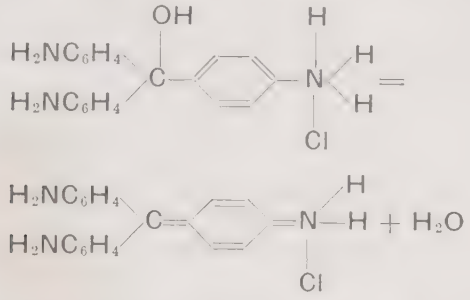
657. In 1856 Perkin discovered accidentally in an investigation which had as its aim the synthesis of quinine, that a violet dye was formed when aniline containing toluidine was oxidized with chromic acid. The manufacture of this dye, which was called *mauve*, marked the beginning of the coal-tar color industry. In 1859 Hofmann prepared *magenta* by oxidizing a mixture of aniline, *o*-toluidine, and *p*-toluidine with less active oxidizing agents than chromic acid, such as nitrobenzene and mercuric chloride. An investigation of the structure of magenta by E. and O. Fischer showed later that the dye is a derivative of triphenylmethane. Mauve has been shown, however, not to be a derivative of this hydrocarbon.

The dyes of this group are not prepared from triphenylmethane, but the synthesis of pararosaniline from the hydrocarbon is of importance, as it established the structure of this dye which is the simplest member of the class. The steps involved in the transformation of triphenylmethane into pararosaniline are indicated by the formulas:

$$(C_6H_5)_3CH \longrightarrow (NO_2C_6H_4)_3CH \longrightarrow (NH_2C_6H_4)_3CH \longrightarrow (NH_2C_6H_4)_3COH$$

Triphenylmethane is converted by cold fuming nitric acid into a trinitro derivative, in which the nitro groups are in the para positions to the methane carbon atom. Reduction converts this compound into the corresponding amine, which is changed

by mild oxidizing agents into tris (aminophenyl) carbinol. This substance, also called pararosaniline, when treated with acids, yields highly colored salts which are dyes. The formation of the salt and the attendant production of color takes place with the elimination of one molecule of water when equal molecular quantities of the base and acid are used. The manner in which the water is eliminated and the structure of the resulting salt have been the subject of much investigation. The view generally accepted at present is that indicated by the formulas:



It is believed that hydrochloric acid adds to one amino group, and that the elimination of water then takes place in such a way that a quinonoid ring is formed. A change in the reverse direction occurs when an alkali is added to a salt of pararosaniline; the salt is decomposed and the free base is formed.

The triphenylmethane dyes are salts formed by the action of acids on certain derivatives of triphenylcarbinol. For this reason these derivatives are called "color bases," although they are, themselves, colorless. By reduction the color bases are converted into the so-called "leuco bases" which are formed as the result of the replacement of the hydroxyl group of the carbinol by hydrogen. The leuco bases may be oxidized to the color bases. In the case of pararosaniline the bases have the following formulas:

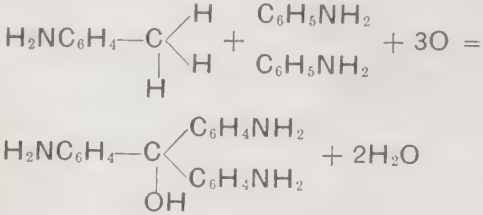
$(H_2NC_6H_4)_3C.H$ — Leuco base

$(H_2NC_6H_4)_3C.OH$ — Color base

The color base having the structure indicated is called the carbonium color base to distinguish it from the true color base which contains a quinonoid ring: $(H_2NC_6H_4)_2C = C_6H_4 = NH_2OH$.

658. Pararosaniline is obtained by heating *p*-toluidine and aniline, in the molecular proportion of one of the former to two

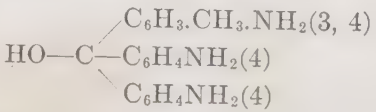
of the latter, with a mild oxidizing agent such as arsenic acid or nitrobenzene. The methyl group of the toluidine furnishes the so-called methane carbon atom:



The color base dissolves in acids and forms a red dye; it may be precipitated from the solution by alkalies.

Pararosaniline can be converted into triphenylmethane; the color base is reduced by zinc and hydrochloric acid to the leuco base, triamino-triphenylmethane, which in turn is converted into triphenylmethane as the result of the replacement of the amino groups by hydrogen through the use of the diazo reaction.

659. Rosaniline is the chief color base of *magenta*. The hydrochloride of the base is generally called magenta or fuchsine, although the acetate is also used under these names. Rosaniline is manufactured by oxidizing a mixture of aniline, *o*-toluidine, and *p*-toluidine, with arsenic acid, mercuric nitrate, or nitrobenzene. The reaction is analogous to that which takes place in the preparation of pararosaniline, of which rosaniline is a methyl derivative with the structure indicated by the following formula:



Acid magenta, or *acid fuchsin*, is the sodium salt of the trisulphonic acid obtained by heating rosaniline with fuming sulphuric acid.

660. Methyl Violet.—By the partial or complete substitution of the hydrogen atoms of the amino groups in pararosaniline and rosaniline by methyl or ethyl groups, violet dyes are obtained, those containing the larger number of alkyl groups yielding the bluer shades. Methyl violet, which is the hydrochloride or the double zinc chloride of pentamethyl-pararosaniline, is prepared by oxidizing dimethylaniline with cupric chloride.

661. Crystal Violet.—The preparation of this dye, which is the chloride of hexamethyl-pararosaniline, illustrates a method of preparing dyes of this class. The compound is manufactured by treating dimethylaniline with carbonyl chloride or tetramethyl-diamino-benzophenone chloride:

$$[(CH_3)_2NC_6H_4]_2CCl_2 + C_6H_5N(CH_3)_2 = ClC[C_6H_4N(CH_3)_2]_3 + HCl$$

The compound formed in this way probably rearranges into one which possesses a quinonoid formula similar to that assigned to the salts of pararosaniline.

662. Spirit Blue.—The introduction of phenyl radicals into the amino groups of rosaniline and pararosaniline leads to the formation of blue-violet and blue dyes. Spirit blue is prepared by heating rosaniline to about 180° with aniline and benzoic acid.

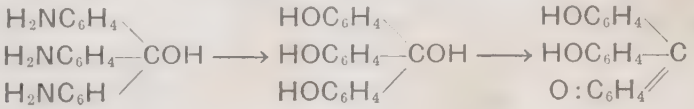
663. Malachite green is an example of a dye derived from diamino-triphenylmethane. It is prepared by heating benzoic aldehyde with dimethylaniline in the presence of a dehydrating agent, and oxidizing the resulting compound with lead peroxide. The formation of the leuco base takes place according to the following equation:

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

The base, which is a tetramethyl-diamino-triphenylmethane, is oxidized to the corresponding carbinol. The dye is usually sold as the double zinc salt $3C_{23}H_{24}N_2HCl.2ZnCl_2.2H_2O$.

664. New Victoria green is a chlorinated malachite green prepared from dichlorobenzoic aldehyde and dimethylaniline. The introduction of halogen leads to the formation of a dye which yields bluer shades of green than malachite green.

665. Rosolic Acid Derivatives.—Certain hydroxyl derivatives of triphenylmethane are highly colored compounds and serve as useful dyes. The structure of these compounds is analogous to that of pararosaniline. When the amino groups of pararosaniline are replaced by hydroxyl groups by means of the diazo reaction, trihydroxy-triphenylcarbinol is first formed and then loses water and passes into pararosolic acid (aurin):

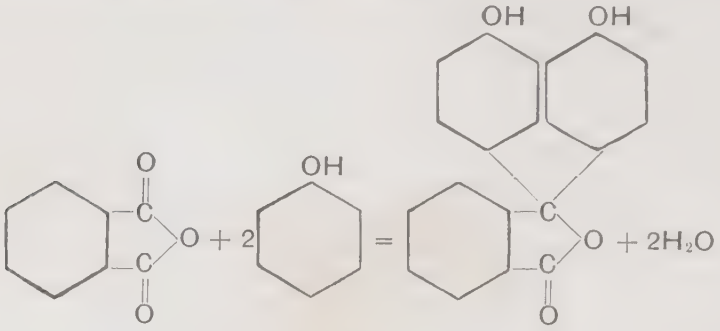


The dye is a red crystalline compound which forms salts with acids and bases. The sodium salt is the *yellow corallin* of commerce. The dye is prepared by heating a mixture of phenol, sulphuric acid, and oxalic acid.

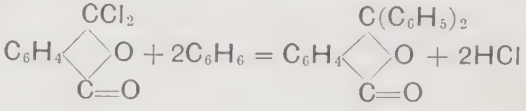
666. Rosolic acid bears the same relation to rosaniline that pararosolic bears to pararosaniline. Derivatives of these coloring matters which contain nitro groups and carboxyl groups are also used as dyes.

667. Phthaleins.—Phenolphthalein, which is prepared by heating a mixture of phenol and phthalic anhydride with a

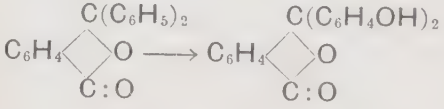
dehydrating agent, is a derivative of triphenylmethane. The equation for the reaction is as follows:



The structure of phenolphthalein has been established by its synthesis from diphenylphthalide, which is prepared from phthalyl chloride and benzene by the Friedel and Crafts reaction:

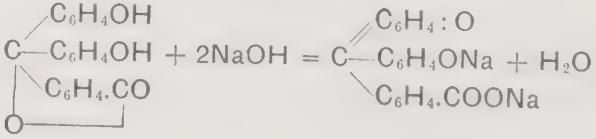


When diphenylphthalide is treated with nitric acid a dinitro derivative is formed. When the nitro groups are replaced by hydroxyl groups by reduction and the diazo reaction, the resulting compound is phenolphthalein:

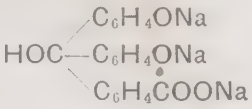


Phenolphthalein is a colorless compound which yields pink salts with alkalies, and is a valuable indicator in acidimetry. It is very sensitive to hydrogen ions, and is accordingly suited to the titration of the weak organic acids.

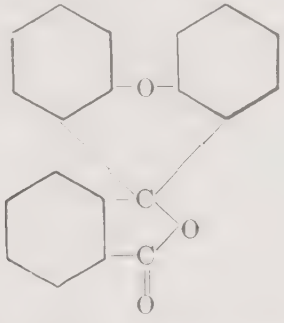
668. The use of phenolphthalein as an indicator is based on the fact that when it is converted into salts by alkalies, a molecular rearrangement takes place as the result of which a colored compound containing a quinonoid group is formed:



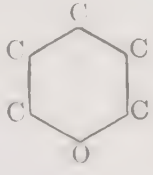
The color of the salts of phenolphthalein and related compounds is considered to be due to the presence in them of the chromophore group $C_6H_4{:}O$. When an acid is added to a solution of the colored salt, phenolphthalein is set free, and the color disappears. In the presence of a large excess of alkali the color of the salt first formed disappears. This change is produced as the result of the reaction of a third molecule of the alkali which destroys the quinonoid grouping. The structure of the salt formed in this way is as follows:



669. Fluoran is formed as a by-product in the preparation of phenolphthalein. In the formation of this compound the condensation of phthalic anhydride with phenol takes place in such a way that the hydrogen atoms eliminated from the phenol are those in the ortho position to the hydroxyl group, whereas in the case of phenolphthalein the hydrogen atoms involved are the ones in the para position. The product formed in this way loses water and the result is fluoran, which has the structure indicated by the following formula:

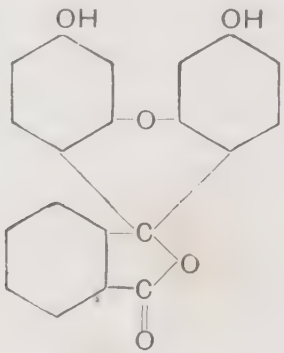


Fluoran dissolves in sulphuric acid to form fluorescent solutions, *i.e.*, solutions which exhibit different colors in transmitted and reflected light. It has been shown that many compounds fluoresce which contain the pyran ring



which is present in fluoran.

670. Fluorescein is a dihydroxyl derivative of fluoran, which is prepared by heating phthalic anhydride with resorcinol. The structure assigned to the compound is as follows:



Dilute solutions of fluorescein in alkalies exhibit a brilliant yellow-green fluorescence.

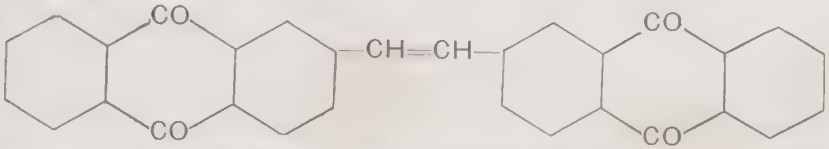
A number of derivatives of fluorescein are useful dyes. *Uranin* is the disodium salt of fluorescein. *Chrysolin* is a salt of benzyl-fluorescein, which is formed from phthalic anhydride and benzyl-resorcinol. It dyes silk and wool a fast yellow, and is used in cotton dyeing. *Eosin* is the disodium salt of tetrabromo-fluorescein, which is prepared by the action of bromine on fluorescein. Its dilute alkaline solution is rose-colored, and exhibits an intense yellow-green fluorescence. Other dyes related to fluorescein are tetrabromo-dichlorofluorescein and various ethers of fluorescein and its substitution products. The dyes of this class produce, on silk and wool, shades from yellow to reddish yellow, cherry-red, and purple.

Vat Dyes

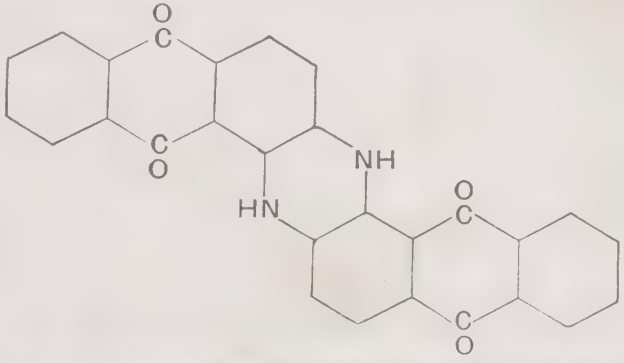
671. When certain derivatives of anthraquinone are fused with sodium hydroxide, colored compounds are formed which can be used to dye cotton without a mordant; as they are very fast to light, acids, and bases they are very valuable and are much used. In order to get the insoluble dye into solution it is treated with an alkaline solution of sodium hydrosulphite, $Na_2S_2O_4$, which reduces the dye and converts it into a soluble salt (**600**). The cloth to be dyed is placed in the vat; when it is removed, the colorless compound which it has absorbed is oxidized

to the original coloring matter. The dyes which are treated in this way are called vat dyes.

Anthraflavone G is a vat dye made by fusing 2-methylanthraquinone with sodium hydroxide and exposing to the air the solution of the compound formed. Two molecules of the ketone are united as the result of the removal of two hydrogen atoms from each of the methyl groups. The structure of the insoluble dye is as follows:



Indanthrene blue R is prepared by fusing 2-aminoanthraquinone with potassium hydroxide and exposing the soluble salt thus formed to the air. It has the following structure:

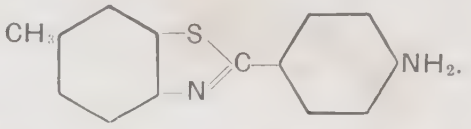


A great variety of dyes have been prepared by fusing with an alkali derivatives of anthraquinone which contain chlorine, alkyl, and other radicals. Condensation in other ways than those illustrated above take place and compounds with very complex structures are obtained. Indigo is the most important vat dye; its structure and synthesis are described later (**707**).

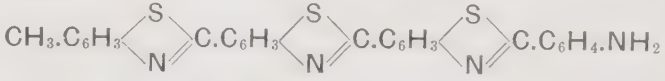
Sulphur Colors

672. When certain amines and phenols are heated with sulphur or with a strong solution of sodium polysulphide, colored substances are formed which have proved to be excellent dyes characterized by great fastness to light, scouring, and acids. The structure of most of these dyes is unknown. They differ from most other dyes by possessing the valuable property of dyeing cotton without a mordant. They are usually applied in a bath of sodium sulphide in which they are soluble. Some are applied in a hydrosulphite bath in the way used with indigo.

673. Primuline, an important dye of this class, is prepared by sulphonating the compound formed by heating *p*-toluidine with sulphur at about 250°. The first reaction which takes place leads to the formation of a compound which appears to have the structure



By the further action of sulphur this compound is converted into one to which the following formula has been assigned:



The product is rendered soluble in water by converting it into a sulphonic acid. Primuline dyes cotton directly a lemon-yellow color. In order to deposit an ingrain color on cotton dyed with primuline, the cloth is first treated with a dilute acidified solution of sodium nitrite. Primuline, which contains an amino group, is thus converted into a diazonium salt. The material is next washed with cold water and immersed in a solution of one of the naphthols, naphthylamines, or their derivatives. Azo compounds are formed in this way directly in the fabric, and as a result various shades of yellow, orange, scarlet, or maroon may be obtained.

674. Sulphur black is prepared by fusing dinitrophenol, $C_6H_3OH(1),(NO_2)_2(2,4)$, with sulphur or by heating it with a strong solution of sodium polysulphide. The intermediate necessary is prepared from chlorodinitrobenzene which is formed by nitrating chlorobenzene. The chlorine atom is readily replaced by the hydroxyl group when the compound is warmed with a solution of caustic soda.

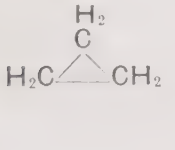
CHAPTER XXVIII

ALICYCLIC COMPOUNDS

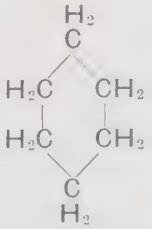
675. The carbocyclic compounds considered in the previous chapters contain one or more benzene rings and exhibit the chemical properties characteristic of the aromatic compounds. Many substances are known in which carbon atoms are united in rings that contain from three to a large number of these atoms. The properties of such compounds, which are designated as *alicyclic*, vary with the state of unsaturation of the atoms in the ring; some show the properties of saturated compounds, and others are similar to the olefins in chemical behavior.

Many substances that occur in nature are members of this class; the more important are the terpenes, camphors, and the naphthenes, which are important constituents of certain petroleums.

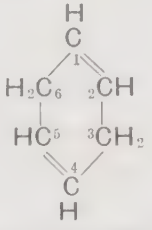
676. Nomenclature of Alicyclic Compounds.—The name of a compound of this class is derived by adding the prefix *cyclo* to the name of the aliphatic hydrocarbon which contains the same number of carbon atoms. To designate the position of substituents and double bonds, the atoms in the ring are numbered. The method is illustrated by the following examples:



Cyclopropane



Cyclohexane

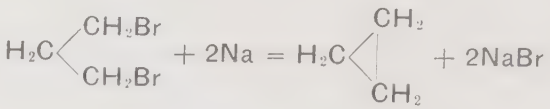


1,4,Cyclohexadiene

Compounds which contain rings made up of CH_2 groups are called cycloparaffins. These like other hydrocarbons, yield alkyl derivatives.

677. Cyclopropane.—It will be recalled that when 1, 2-dibromopropane, $CH_3CH_2BrCH_2Br$, is treated with a metal the two halogen

atoms are removed, and propylene, $CH_3CH{=}CH_2$, is formed. If the bromine atoms are not in combination with adjacent carbon atoms a different kind of reaction takes place; 1,3-dibromopropane yields cyclopropane when the halogen atoms are removed by sodium:



Cyclopropane is a gas, which after liquefaction boils at $-34.4°$.

Although the formula assigned to the hydrocarbon is that of a saturated compound, it reacts with bromine slowly and forms 1, 3-dibromopropane, and with hydriodic acid it yields *n*-propyl iodide. The explanation given of the fact is that a ring compound of three carbon atoms is unstable and is broken by such active reagents as the halogens.

678. Baeyer's Strain Theory.—This theory postulates that the stability of rings made up of carbon atoms is dependent upon the greater or less distortion of the valencies of the carbon atoms that are united in the formation of the ring. According to the present structure theory of organic compounds the valency forces of the carbon atom in such compounds are normally directed toward the angles of a tetrahedron, in the center of which is situated the carbon atom. This view leads to the conclusion that the angle between the direction of the valency forces in methane, for example, is 109° 28′. When carbon atoms are united in rings there is more or less distortion of the direction of the forces between the atoms.

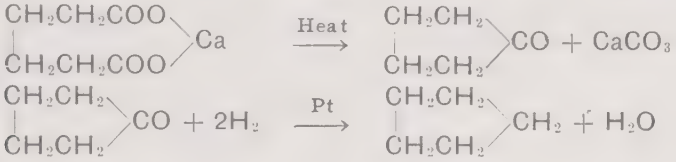
In the case of cyclopropane the angle between the valencies is 60°, since they form a triangle made up of 3 carbon atoms. The distortion of each valency in this case is $\frac{1}{2}(109° 28' - 60°) = -24° 44'$. As the angle in cyclopropane is less than that in methane the value of the distortion is written with a minus sign.

According to this theory the instability of the cyclopropane ring, which is broken by bromine, is a consequence of the strain set up in the molecule as the result of the displacement of the valency forces from their normal directions.

The stability of the cyclic hydrocarbons increases as the distortion of the valencies decreases. The values of the latter

for some of these compounds are as follows: cyclobutane, $(CH_2)_4$, $-9°\ 44'$; cyclopentane, $(CH_2)_5$, $-0°\ 44'$; cyclohexane, $(CH_2)_6$, $+5°\ 16'$.

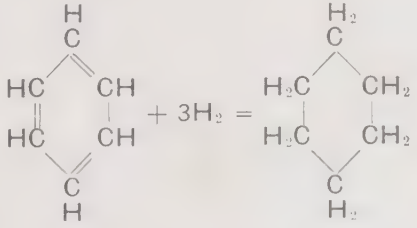
679. Cyclopentane.—The ease with which cyclo compounds containing five carbon atoms in the ring can be prepared is in accord with the "strain theory." A convenient method of preparing cyclopentane is illustrated by the following equations:



When the calcium salt of adipic acid is heated to a high temperature a ketone, *cyclopentanone* (b.p. 130.6°) is formed. The latter on reduction is converted into cyclopentane (b.p. 49.5°).

Cyclopentane is stable, resembles pentane in chemical properties, and yields similar derivatives. Cyclopentanone shows the characteristic reactions of aliphatic ketones. For example, it can be reduced to a secondary alcohol, *cyclopentanol*, and it reacts with hydroxylamine, etc.

680. Cyclohexane can be prepared by the addition of hydrogen to benzene:



The reduction can be accomplished by the method of Sabatier and Senderens, which consists in passing hydrogen and the vapor of the hydrocarbon over finely divided nickel heated between 150° and 200°. The reduction can be effected at room temperature by passing hydrogen into benzene in which platinum black is suspended. Toluene and other aromatic hydrocarbons can be converted similarly into homologues of cyclohexane. On account of this fact cyclohexane and its alkyl derivatives are sometimes called *hydroaromatic hydrocarbons*.

The boiling point of cyclohexane, 81.4°, is close to that of benzene, 79.6°; the two compounds melt at 6.5° and 5.5°, respectively. The difference in structure of the two hydrocarbons has a greater effect on density; C_6H_{12}, $0.779^{\frac{20°}{4°}}$, C_6H_6, $0.878^{\frac{20°}{4°}}$. The chemical properties of cyclohexane and its derivatives are similar to those of the analogous paraffin compounds. When cyclohexane is heated with fuming sulphuric acid it is oxidized and sulphonic acids of benzene are formed.

Cyclohexanol (b.p. 161.5°) is prepared by reducing phenol. It shows the properties characteristic of secondary alcohols and is a convenient source in the preparation of many derivatives of cyclohexane.

681. Menthane, $C_6H_{10}(CH_3)(iso\text{-}C_3H_7)(1; 4)$ is para-methyl-isopropyl-cyclohexane. It is of interest as many important compounds that occur in nature are derived from it. *Menthol*, the principal constituent of the oil of peppermint, is a derivative of menthane which contains a hydroxyl group in combination with the carbon atom ortho to the isopropyl radical.

682. Naphthenes.—This name is given to the alicyclic hydrocarbons that occur in certain petroleums, notably those found in Russia and California. It is probable that the higher-boiling naphthenes contain two or more cyclohexane rings in combination, which are united to aliphatic radicals.

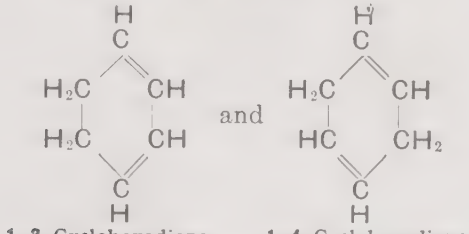
683. The properties of some of the cycloparaffins are listed in the following table:

CYCLOPARAFFINS

Name	Formula	Melting point, °C.	Boiling point, °C.	Density, $\frac{20°}{4°}$	Heat of combustion, kg. calories
Cyclopropane	$(CH_2)_3$	−126.6	−34.4	$0.720^{-79°}$	496.8
Cyclobutane	$(CH_2)_4$	− 50	13	$0.703^{0}_{4°}$	
Cyclopentane	$(CH_2)_5$	− 93.3	49.5	0.754	783.6
Cyclohexane	$(CH_2)_6$	6.5	81.4	0.779	939
Cycloheptane	$(CH_2)_7$	− 12	118.1	0.811	1,087
Cyclooctane	$(CH_2)_8$	14.4	150.6	0.839	
Cyclononane	$(CH_2)_9$	.....	172	$0.773^{10°}_{4°}$	

684. Unsaturated Alicyclic Hydrocarbons.—A number of hydrocarbons of this class are known. They can be prepared from the cycloparaffins by reactions analogous to those used to convert paraffins into olefins. For example, *cyclohexene* (b.p. 83°) can be prepared by dehydrating cyclohexanol, or by the action of an alcoholic solution of potassium hydroxide on bromocyclohexane.

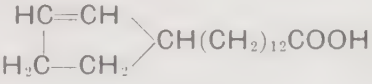
Cyclohexadiene exists in two forms:



1, 3–Cyclohexadiene (b.p. 78.5°) and **1, 4–Cyclohexadiene** (b.p. 85.5°)

These hydrocarbons are characterized by great chemical reactivity. 1, 3-Cyclohexadiene, in which the double bonds are conjugated (**51**), absorbs moisture from the air, unites directly with oxygen, and polymerizes on standing.

Chaulmoogra oil, which is used in combating leprosy, contains as its chief constituents two acids that are derived from cyclopentene. One of these, *chaulmoogric acid*, has the following formula:



The other, *hydnocarpic acid*, has a similar structure, but contains 10 CH_2 groups in a straight chain instead of 12.

CHAPTER XXIX

TERPENES AND CAMPHORS

685. The hydrocarbons of the composition $(C_5H_8)_x$, present in plants, are called *terpenes*. The more important members of the class have the formula $C_{10}H_{16}$, and are obtained from the sap of coniferous trees and from fruits of the citrus variety; they are the principal constituents of oil of turpentine and of many essential oils. With few exceptions the terpenes are liquids; some are optically active. They polymerize when treated with sulphuric acid, and form addition products with bromine, hydrochloric acid, and water. The terpenes can be converted into cymene, and like this hydrocarbon yield *p*-toluic acid and terephthalic acid when oxidized.

The terpenes and their derivatives have been carefully studied in an endeavor to determine the relation which exists between the structural configurations of these important substances. Some of the hydrocarbons are unsaturated aliphatic compounds; to this class belong isoprene, C_5H_8, which is called a hemiterpene, and anhydrogeraniol,

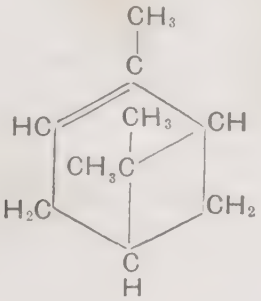
$$(CH_3)_2C:CH.CH_2.CH_2.C(CH_3):C:CH_2$$

of which geranial (**197**) is a derivative. Most of the terpenes, however, are *alicyclic compounds*, some of which contain two rings. Only a few of these compounds will be considered here. On account of the complexity of the subject it is impossible to discuss briefly the evidence in favor of the constitutional formulas which have been assigned to the terpenes.

686. Pinene, $C_{10}H_{16}$, is the principal constituent of the oil of turpentine; that obtained from the American oil is dextrorotatory, and that from the German and French oil is levorotatory.

Turpentine, which is the sap of coniferous trees, contains in addition to terpenes a non-volatile compound of unknown

structure, called abietic anhydride. When the sap is distilled with steam, there are obtained oil of turpentine and abietic acid, $C_{19}H_{28}O_2$, which is nonvolatile; when the distillation is made without steam the residue is called *rosin or colophony*. Pinene boils at 154° and has the specific gravity $0.878^{20°}_{4°}$. Pinene is present in the oils of rosemary, lemon, sage, juniper, thyme, and anise, and in other essential oils. The structural formula assigned to pinene is as follows:

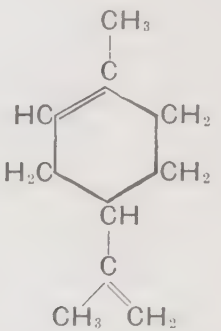


Pinene forms with one molecule of dry hydrogen chloride an addition product, which is called artificial camphor (m.p. 128°) on account of the fact that it resembles camphor in appearance and odor. When this compound is heated with alcoholic potash or with a mixture of anhydrous sodium acetate and glacial acetic acid, hydrogen chloride is eliminated and *camphene*, an isomer of pinene, is formed. Camphene, the structure of which is not known, melts at 50°; it is converted into camphor, $C_{10}H_{16}O$ (**689**), when oxidized with chromic acid. *d*-Camphene is found in ginger; *l*-camphene, in turpentine and in citronella and other essential oils.

687. Limonene, $C_{10}H_{16}$, occurs in two optically active varieties; the dextro compound (b.p. 177°) is present in the oils obtained from oranges, lemons, and caraway. *l*-Limonene is obtained from the oil distilled from the leaves of a variety of pine. When the two varieties are mixed in equal amounts the racemic modification formed is identical with *dipentene*, a compound which is formed when pinene and other terpenes are heated to a high temperature. Dipentene occurs in the volatile oil of the camphor tree and in Russian and Swedish turpentines.

The limonenes add two molecules of hydrogen chloride and four atoms of bromine, and form crystalline addition products

with nitrosyl chloride, NOCl. The formula assigned to limonene is:



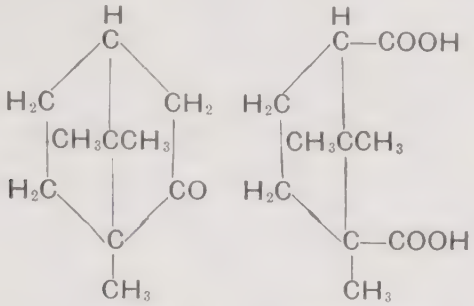
This formula is in accord with the fact that the hydrocarbon can be converted into cymene (**445**), that it unites with two molecules of hydrogen chloride, and that it exists in optically active modifications, one of the carbon atoms of the ring being asymmetric.

Camphors

688. The camphors are oxygen derivatives related to the terpenes; they have the formulas $C_{10}H_{16}O$, $C_{10}H_{18}O$, and $C_{10}H_{20}O$, are associated with terpenes in plants, and are constituents of many essential oils. The camphors are solid crystalline substances, which are volatile with steam, sublime at low temperatures, and possess characteristic odors. Like the terpenes they are readily converted into benzene derivatives; when ordinary camphor is warmed with phosphorus pentoxide, cymene is formed.

689. Camphor, $C_{10}H_{16}O$, sometimes called *Japan camphor* or *laurinol*, is obtained by distilling with steam the wood or leaves of the camphor tree; it melts at 179°, boils at 209°, and is dextrorotatory. The chemical properties of camphor are those of a ketone; it forms an oxime with hydroxylamine, its oxygen atom is replaced by two chlorine atoms when it is treated with phosphorus pentachloride, and it is converted by reducing agents into borneol, which is a secondary alcohol. By the loss of water, camphor passes into cymene (**445**), and by the loss of two hydrogen atoms into carvacrol (**544**). The chief prod-

uct of the oxidation of camphor is camphoric acid, $C_{10}H_{16}O_4$. The formulas assigned to these two substances are as follows:



Camphor Camphoric acid

Camphene is converted by oxidation into camphor; the relation between the compounds is clear from the structural formulas which have been given.

Among the compounds isomeric with camphor may be mentioned *fenchone*, which is present in fennel oil, and *pulegone* which is a constituent of the oil of pennyroyal.

690. Borneol, $C_{10}H_{18}O$, (m.p. 208.6°) is a camphor which is found in certain trees grown in Borneo and Sumatra; it is also present in the oil of valerian and the oil of rosemary. As has been stated, it is formed by reducing ordinary camphor. It yields camphor on oxidation and is converted by dehydrating agents into camphene. It is, accordingly, the secondary alcohol formed by reducing the carbonyl group in camphor. It can be prepared by the hydrolysis of the hydrochloric acid addition product of pinene. It is possible, therefore, to effect the synthesis of camphor from turpentine.

Cineole, *terpineol*, and *thujone* are isomers of borneol which occur in certain essential oils. *Menthol* (mint camphor), $C_{10}H_{20}O$, the chief constituent of the oil of peppermint, has been mentioned (**681**).

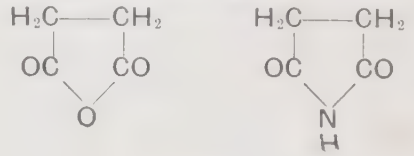
CHAPTER XXX

HETEROCYCLIC COMPOUNDS

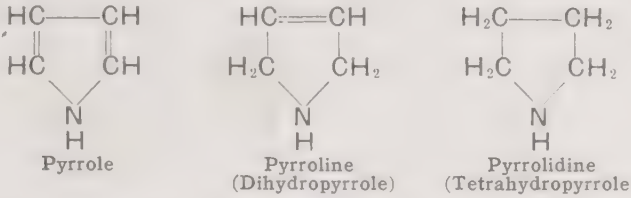
691. Compounds which contain atoms joined in a ring are classified as *homocyclic* or *heterocyclic* compounds; to the former class belong the substances in which the ring is made up of atoms of but one element; and to the latter, those containing two or more elements in the ring. Benzene and naphthalene are homocyclic compounds; as the rings in these cases consist of carbon atoms, the hydrocarbons are sometimes called *carbocyclic* compounds. Succinic anhydride and succinimide are heterocyclic compounds as the rings present in these substances contain oxygen and nitrogen, respectively, in addition to carbon.

Many heterocyclic compounds of complex structure occur in nature, and many have been synthesized. Most of the basic nitrogenous substances which occur in plants and are known as alkaloids are heterocyclic compounds. When coal is subjected to destructive distillation a part of the nitrogen present is converted into ammonia, and a part into cyclic compounds which contain nitrogen as a constituent of the ring. Heterocyclic compounds are also obtained from "Dippel's oil," which is a product of the distillation of bones. From these sources are obtained pyridine, C_5H_5N; picoline, $CH_3.C_5H_4N$; quinoline, C_9H_7N; etc.

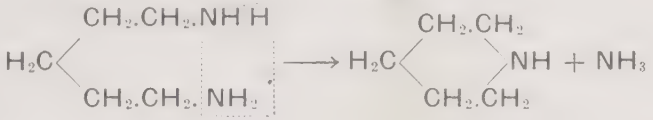
692. It is possible to prepare ring compounds of many types as the result of the elimination of atoms or groups from straight-chain compounds, the formation of rings containing five or six atoms being most easily accomplished. It will be recalled that succinic acid is converted into its anhydride when heated, and that succinamide under similar conditions yields succinimide. The formulas of these compounds are as follows:



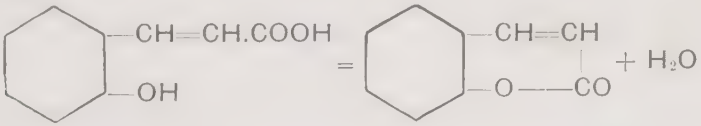
By reduction succinimide may be converted into compounds of the following formulas:



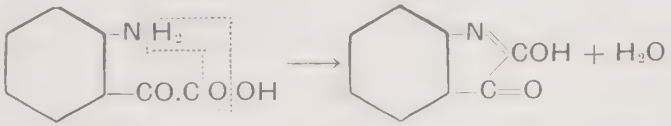
Ring compounds are formed when the salts of certain diamines are distilled. In this way piperidine is formed from pentamethylenediamine:



Ring compounds are also readily formed from ortho derivatives of benzene. Thus, *o*-hydroxycinnamic acid loses water and passes into *coumarin*, a constituent of tonka beans, which is used in the preparation of perfumery and as an adulterant in vanilla extract:



o-Aminobenzoylformic acid loses water spontaneously and isatin is formed:

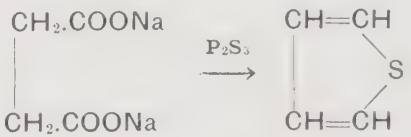


A great variety of heterocyclic compounds containing nitrogen or other elements have been investigated, but only a few will be described here.

693. Thiophene, C_4H_4S, is present to the extent of about 0.5 per cent in the crude benzene obtained from coal tar. It is a liquid which resembles benzene closely in physical and chemical properties; it boils at 85° and has the specific gravity $1.065^{20°}_{4°}$. When thiophene is treated with isatin (**707**) and sulphuric acid a blue coloration is formed. The production of color in this

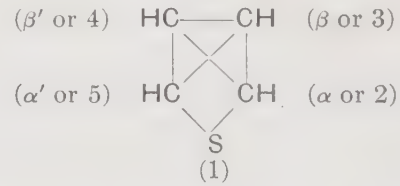
way, the so-called *indophenin reaction*, led to the discovery of thiophene by Victor Meyer. Before thiophene was discovered it was thought that the reaction was characteristic of benzene. A certain sample of the hydrocarbon failed to give the test. On investigation it was found that the benzene used had been prepared from benzoic acid. As benzene obtained from coal tar gave the test, it was evident that the color reaction was produced by a substance mixed with the hydrocarbon. When benzene containing thiophene is shaken with concentrated sulphuric acid, the thiophene is more rapidly converted into a sulphonic acid than is the benzene. Thiophene is obtained from the sulphonic acid prepared in this way by heating the latter with water under pressure.

694. Thiophene has been synthesized by heating sodium succinate with phosphorus trisulphide:



It is also formed when acetylene is passed over iron pyrites, FeS_2, at 300°; the liquid obtained contains about 50 per cent of thiophene.

As thiophene resembles closely benzene in chemical properties, a centric formula similar to that of benzene has been proposed for it:



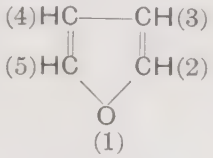
(1)

Thiophene possesses the characteristics of aromatic compounds; it is converted into nitro compounds by nitric acid, into halogen derivatives by bromine and chlorine, into sulphonic acids by sulphuric acid, and condenses with acyl chlorides in the presence of aluminium chloride to form a ketone. It will be recalled that compounds which behave in this way are classed as aromatic.

Homologues of thiophene occur in coal tar; they may be prepared by Fittig's synthesis and in other ways. Their proper-

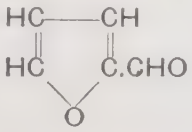
ties are similar to those of the analogous benzene derivatives; for example, thiotolene (methyl thiophene) is converted into thiophene carboxylic acid by oxidizing agents:

695. Furfuran (furan), C_4H_4O, resembles thiophene in structure, the sulphur atom in the latter being replaced by oxygen:



It occurs in pine-wood tar, and is formed in small quantities when cane sugar is distilled with lime; it boils at 31°.

696. Furfural, $C_4H_3O.CHO$, is an aldehyde derived from furfuran. Its syntheses and reactions lead to the conclusion that it has the structure represented by the following formula:



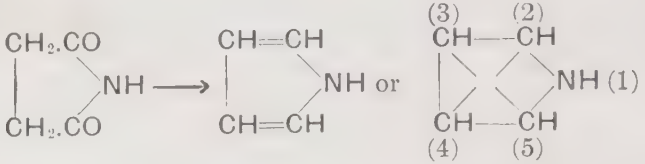
Furfural, which is also called furaldehyde, is formed when pentoses are heated with dilute sulphuric acid or dilute hydrochloric acid. Since it can be readily prepared at a cheap price in this way from cornstalks, efforts have been made to find applications for the aldehyde; its use as a paint remover has been patented recently.

Furfural yields an intense red dye when treated with aniline and hydrochloric acid; it serves thus as a convenient test for pentoses and pentosans. Furfural is a liquid which possesses an agreeable odor and boils at 161.7°. It possesses the characteristic properties of an aromatic aldehyde.

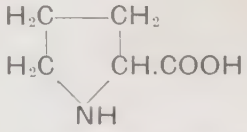
697. Furoic acid (pyromucic acid), $C_4H_3O.COOH$, is formed as the result of the oxidation of furfural. As its name implies it is produced by the distillation of mucic acid, $COOH(CHOH)_4COOH$. Furoic acid melts at 133° and sublimes readily. When heated at 275° it loses carbon dioxide and is converted into

furan; it is sulphonated by fuming sulphuric acid. The unsaturation of the ring resembles that in the olefins; it adds four bromine atoms and is oxidized by Baeyer's reagent.

698. Pyrrole, $C_4H_4.NH$, occurs in coal tar and in bone oil. It is formed as the result of the distillation of the ammonium salt of saccharic acid, and by the reduction of succinimide with zinc dust:



Pyrrole is an oil with a fragrant odor resembling that of chloroform; it boils at 131° and has the specific gravity 0.948 $\frac{20°}{4°}$. It imparts a carmine-red coloration to pine-wood shavings in the presence of hydrochloric acid. Pyrrole is a weak base and possesses to some extent the properties of a secondary amine. It yields substitution products with the halogens; in these reactions the ring appears to possess aromatic properties, and the centric formula given above is preferred. Pyrrole, on the other hand, is resistant to strong acids and does not yield sulphonic acids and nitro compounds; in this respect it does not show aromatic properties. When warmed with potassium hydroxide it yields the compound C_4H_4NK. Pyrrole is obtained as one of the decomposition products of proteins, chlorophyll, and certain alkaloids. It yields on reduction pyrroline, C_4H_6NH, and pyrrolidine, C_4H_8NH. The carboxyl derivative of the latter having the formula



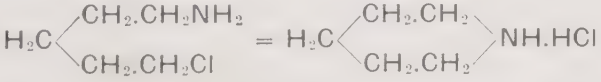
is known as proline; it is formed as the result of the hydrolysis of many proteins.

699. Pyridine, C_5H_5N, and its homologues are the basic constituents of the "light oil" obtained from coal-tar distillate. They are separated from the hydrocarbons in the oil by treating the latter with sulphuric acid. The pyridine bases which dissolve are recovered from solution by treatment with an

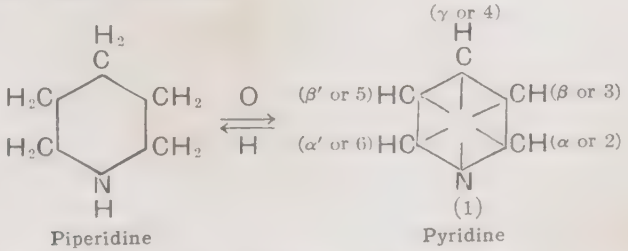
alkali. Pyridine is also obtained from bone oil. When bones which have not been deprived of adhering fat are subjected to distillation, an oil that contains a large number of nitrogen compounds is obtained. When heated to the temperature used in the distillation, the fat present is, in part, converted into acrolein, which yields nitrogenous compounds with the ammonia and other basic substances formed as the result of the decomposition of the proteins present in the bones. Pyridine is present in tobacco smoke and in small quantities in commercial ammonia.

Pyridine is a liquid, miscible with water, which possesses a characteristic, unpleasant odor; it boils at 115.3° and has the specific gravity $0.982^{20°}_{4°}$.

700. Pyridine has been synthesized in a number of ways which lead to definite views of its structure. When an aqueous solution of ϵ-chloroamylamine is warmed, the hydrochloride of piperidine, which is hexahydropyridine, is formed. This fact and other syntheses lead to the view that the reaction which takes place is best interpreted as follows:



As piperidine can be oxidized to pyridine, and pyridine is readily reduced by sodium and alcohol to piperidine, the relation between the two compounds is assumed to be that represented by the following formulas:



Piperidine Pyridine

Pyridine is a tertiary amine; its aqueous solution shows a weakly alkaline reaction and precipitates the hydroxides of metals, some of which are soluble in an excess of the amine. Salts of pyridine like those of other amines form characteristic double salts with metallic halides. The ferrocyanide of pyridine and the addition product of pyridine and mercuric chloride are difficultly soluble in water; these compounds are used in the

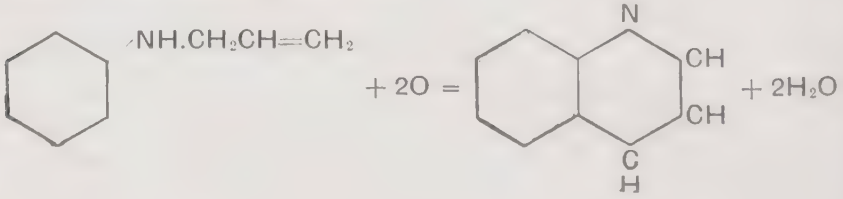
purification of the base. Pyridine is a very stable compound; it can be heated with nitric acid or chromic acid without undergoing change but at 330° it is converted by a mixture of nitric acid and fuming sulphuric acid into 3-nitropyridine, a colorless compound that melts at 41° and boils at 216°. At a high temperature pyridine is converted into a sulphonic acid by sulphuric acid. Chlorine and bromine form addition products, *e.g.*, $C_5H_5N.Cl_2$, at the ordinary temperature; when these are heated to above 200°, substitution products are formed. The hydroxyl derivative of pyridine is made by fusing the sulphonic acid with sodium hydroxide; it resembles phenol in chemical properties. The three possible carboxyl derivatives of pyridine are known. The α-acid is called picolinic acid; the β-acid, nicotinic acid (**712**); and the γ-acid, isonicotinic acid.

Piperidine, $C_5H_{10}NH$, is prepared by the electrolytic reduction of pyridine. It is one of the products of the hydrolysis of piperine, the essential principle of pepper. Piperidine boils at 105.8° and possesses a pepper-like odor; it is a much stronger base than pyridine. It has been used as an accelerator in the vulcanization of rubber.

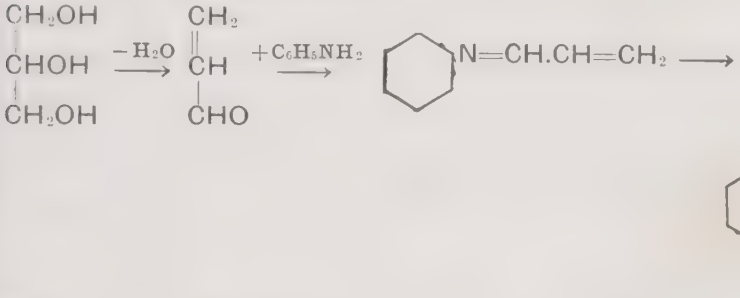
701. Homologues of Pyridine.—Many homologues of pyridine have been obtained from bone oil and coal tar or by syntheses from other compounds. The methyl derivatives of pyridine are called *picolines*, the dimethyl derivatives are called *lutidines*, and those having the formula $C_8H_{11}N$ are called *collidines*. As in the case of toluene and the xylenes, the side chains are converted into carboxyl groups by oxidation.

702. Quinoline, C_9H_7N, is one of the products of the destructive distillation of quinine; it is present in coal tar and bone oil. Quinoline is a liquid of characteristic odor, which boils at 237° and has the specific gravity $1.093^{20°}_{4°}$.

Quinoline has been synthesized by methods which lead to a definite view of its structure. It is formed when allyl aniline is passed over heated lead oxide:

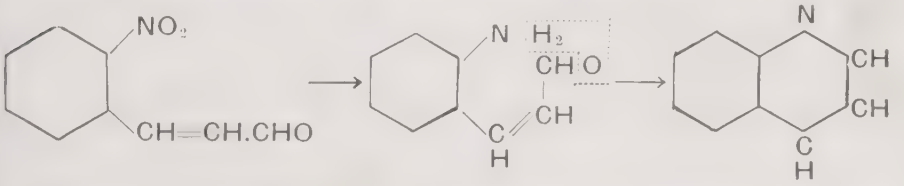


In the *Skraup synthesis* quinoline is formed by heating together aniline, glycerol, and nitrobenzene in the presence of sulphuric acid, which acts as a dehydrating agent. It is possible that the glycerol is first converted into acrolein, which condenses with aniline to form acrolein-aniline; the latter is oxidized by the nitrobenzene to quinoline. These transformations are indicated by the following formulas:

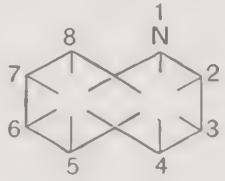


Homologues of quinoline have been prepared by replacing aniline by its substitution products in the Skraup synthesis.

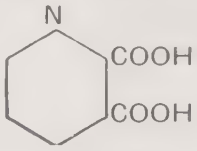
A third synthesis of quinoline is also of interest. When *o*-nitrocinnamic aldehyde is reduced, the amino derivative formed spontaneously loses water and passes into quinoline:



These syntheses indicate that the relation between the structure of quinoline and that of naphthalene is similar to that between the structures of pyridine and benzene; in both cases one CH group may be considered as replaced by a nitrogen atom. On account of the aromatic properties of quinoline the centric formula is usually assigned to it. The substitution products are indicated by assigning a number to each atom in the ring:

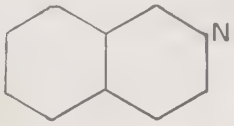


703. Quinoline shows the properties of a tertiary amine. As it contains a pyridine ring, it resembles the latter in chemical properties. When oxidized the benzene ring is destroyed; the dicarboxylic acid which is formed, called quinolinic acid, has the structure represented by the formula



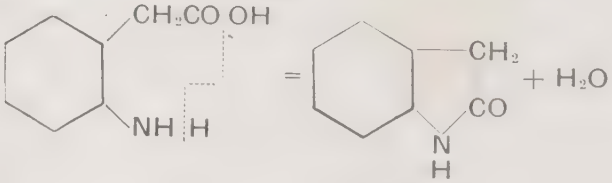
Quinolinic acid is converted into nicotinic acid, β-pyridine-carboxylic acid, when heated, and into pyridine when distilled with lime. These facts are additional evidence of the structure assigned to quinoline.

704. Isoquinoline, C_9H_7N, is present in coal tar. Its odor is similar to that of quinoline; it melts at 23° and boils at 243°. Syntheses of isoquinoline indicate that the structure should be represented by the following formula:



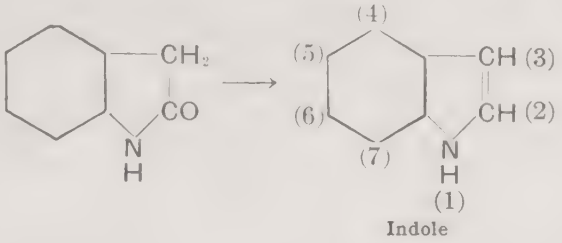
A number of alkaloids are derivatives of isoquinoline.

705. Indole, C_8H_7N, is of interest on account of its relation to indigo (**707**), and the fact that it is the product of the decomposition of certain proteins. Syntheses of indole lead to the conclusion that it is made up of a benzene nucleus condensed with a pyrrole nucleus. When *o*-nitrophenylacetic acid is reduced with tin and hydrochloric acid the aminophenylacetic acid formed loses water spontaneously and passes into oxindole:



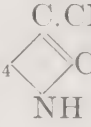
Oxindole

Oxindole is converted into indole when distilled with zinc dust:



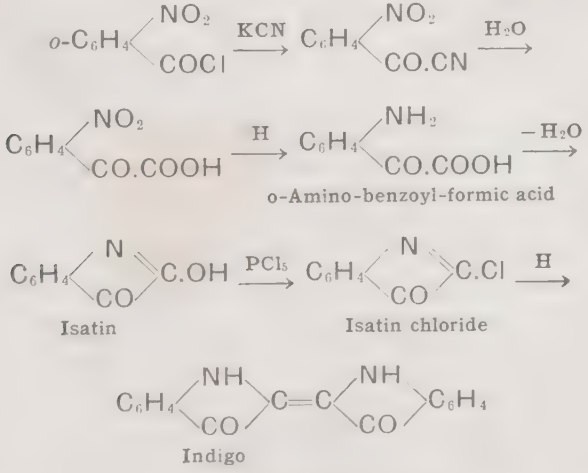
Indole

Indole thus appears to be closely related to benzene and to pyrrole. Its chemical properties are in accord with this view of its structure. Indole is a weak base and like pyrrole gives a red coloration with a pine-wood shaving which has been moistened with hydrochloric acid.

706. Skatole, which is 3-methyl indole, C_6H_4  , is

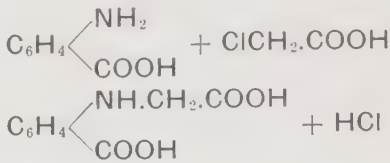
present in faeces, and is formed as the result of the putrefaction of certain proteins. It has a characteristic, disagreeable odor.

707. Indigo (indigotin, indigo blue), $C_{16}H_{10}N_2O_2$, is a valuable blue dye, which is related in structure to the compounds just described. A number of syntheses of the dye which furnish evidence of its constitution have been effected; the one involving the preparation of indigo from isatin is important. The steps in the synthesis are indicated by the following formulas:

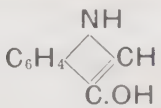


When *o*-nitrobenzoylformic acid is reduced, the amino compound formed loses water spontaneously and passes into isatin. Reduction of isatin chloride with zinc and acetic acid yields indigo.

708. Indigo is manufactured in large quantities by a synthesis which involves the use of naphthalene and acetic acid. From the former, anthranilic acid (**626**) is prepared; and from the latter, chloroacetic acid. These compounds react to form phenylglycocol-*o*-carboxylic acid:

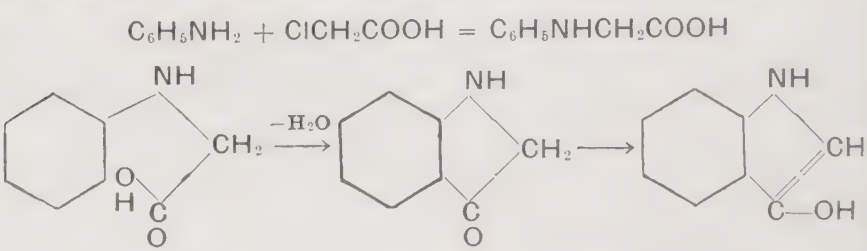


Fusion with sodium hydroxide converts the acid into indoxyl



which is oxidized to indigo in alkaline solution by air.

It is also manufactured by fusing phenylglycine with sodium amide, $NaNH_2$, and oxidizing the salt of indoxyl with air:



709. Indigo is obtained from the glucoside *indican*, which occurs in certain plants grown in India, Java, and other countries. When the leaves of the indigo plant are stirred with warm water the glucoside is extracted. An enzyme present in the leaves converts this compound into glucose and indoxyl, which in turn is oxidized by the air to indigo. The product obtained in this way is a mixture of indigo blue, indigo brown, indigo red, and other coloring matters. Indigotin is a dark-blue compound, insoluble in water and alcohol, which can be crystallized from aniline.

When indigo is treated with reducing agents it takes up two atoms of hydrogen and forms indigo white, $C_{16}H_{12}N_2O_2$, a compound which dissolves in alkalies and is converted by air into indigo. The reducing agent often used is a solution of calcium hydrosulphite, CaS_2O_4, which is prepared by treating zinc hydrosulphite with lime. The fabric to be dyed is immersed in an alkaline solution of indigo white and then exposed to the air, when the blue dye is formed.

The symmetrical dibromo derivative of indigo is the dye called *Tyrian purple* by the Greeks. It was obtained by them from a certain variety of mollusc. Thio-indigo has a reddish-blue color; it contains two sulphur atoms in place of the NH groups in indigo.

Alkaloids

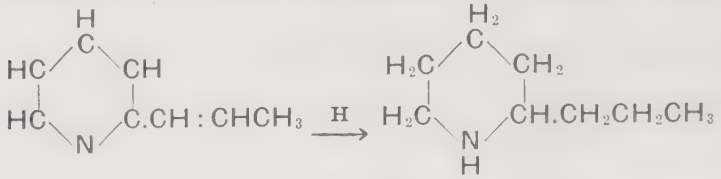
710. The term *alkaloid* is applied to certain basic nitrogenous constituents of plants. The alkaloids differ widely in structure; some like muscarine (**223**) are aliphatic compounds, others like caffeine (**726**) contain a ring of carbon and nitrogen atoms and are related to uric acid. The alkaloids which are described briefly here are related to heterocyclic compounds, chiefly pyridine, quinoline, and isoquinoline. Most alkaloids have a marked physiological effect and many are poisonous; they are the so-called "active principles" of many plants.

With few exceptions the alkaloids are solids which are insoluble in water and crystallize from organic solvents. They are optically active and form salts with acids by direct addition, most of the alkaloids being tertiary amines. On account of the use of alkaloids in medicine their qualitative identification has been carefully studied. Most of the members of this class of compounds are precipitated from their solutions in acids by the so-called *general alkaloidal reagents;* among these are tannin, phosphomolybdic acid, phosphotungstic acid, picric acid, and potassium mercuric iodide and similar double salts. Many alkaloids give characteristic color reactions useful in their identification, when treated with acids, chlorine, and other inorganic reagents. Only a few compounds will be mentioned here.

711. Coniine, $C_8H_{17}N$, the alkaloid of hemlock, is of interest on account of the fact that it was the first natural alkaloid synthesized. Its preparation was effected by condensing α-pic-

oline with aldehyde and reducing the resulting product by means of sodium and alcohol:

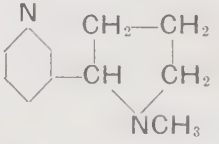
$$NC_5H_4.CH_3 + OHC.CH_3 = NC_5H_4.CH:CH.CH_3 + H_2O$$



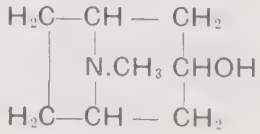
The α-propyl-piperidine prepared in this way differed from coniine in being inactive. By the crystallization of the tartrate of the base two optically active forms were obtained; the dextrorotatory form proved to be identical with the natural alkaloid. Coniine is a colorless liquid which boils at 166.5°; it possesses a penetrating odor and is poisonous.

712. Nicotine, $C_{10}H_{14}N_2$, is the alkaloid of tobacco. It is a liquid which boils at 247° and is miscible with water; it is odorless when pure, but on standing develops a tobacco-like odor and turns brown. Nicotine is converted by oxidizing agents into nicotinic acid, a fact which indicates that the alkaloid is a β-substitution product of pyridine.

The synthesis of nicotine has shown that the group substituted in the β-position is a pyrrolidine ring (**692**), in which the hydrogen atom joined to the nitrogen atom has been replaced by a methyl radical:

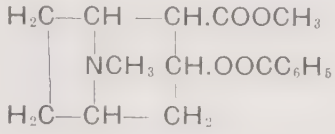


713. Atropine, $C_{17}H_{23}NO_3$, is the principal alkaloid of the deadly nightshade; it melts at 115.5°. It causes dilation of the pupil of the eye and is used by oculists. When heated with a solution of sodium hydroxide, atropine yields tropine, $C_8H_{15}NO$, and tropic acid, $CH_2OH.CHC_6H_5.COOH$. The following formula is assigned to tropine:



Atropine is considered to be the ester formed as the result of the interaction of tropine, which contains an alcoholic hydroxyl group and tropic acid; it is formed from these substances under the catalytic influence of hydrochloric acid.

714. Cocaine, $C_{17}H_{21}NO_4$, is obtained from cocoa leaves. It is crystalline, melts at 98°, and is levorotatory. It is used in the form of a salt as a local anesthetic. Cocaine appears to be a derivative of tropine. The structure of cocaine is represented by the formula:



When it is heated with water in the presence of acids the two ester linkings are broken, and methyl alcohol and benzoic acid are formed; the carboxyl derivative of tropine, which results, is called *ecgonine.*

715. Quinine, $C_{20}H_{24}N_2O_2$, is the most important alkaloid of "Peruvian bark," from which 24 alkaloids have been isolated. Quinine melts at 175°. It is used as an antipyretic. Quinine appears to be a substitution product of a compound made up of a quinoline ring in combination with a ring similar to tropine. It contains a methoxyl group, hydroxyl group, and two tertiary nitrogen atoms.

The structure of *cinchonine* is similar to that of quinine; it differs from the latter in that it has a hydrogen atom in the place of the methoxyl group of quinine. Several of the alkaloids of this group have been synthesized from derivatives of piperidine and quinoline.

716. Strychnine, $C_{21}H_{22}N_2O_2$, is present in the seeds of *Strychnos nux-vomica.* It is excessively poisonous; in very small doses it is a powerful stimulant; larger doses cause death, which is preceded by violent contraction of the muscles. Strychnine melts at 268°. It is converted by fusion with potassium hydroxide into quinoline and indole, and by distillation with lime into β-picoline. *Brucine,* $C_{23}H_{26}N_2O_4$, occurs in nux vomica with strychnine, which it resembles in physiological effect. It differs in structure from strychnine in having two hydrogen atoms replaced by methoxyl groups.

717. Morphine, $C_{17}H_{19}NO_3$, is the principal alkaloid of opium, which contains a large number of substances, such as fats, resins, acids, and gums in addition to 20 alkaloids which have been identified. Opium is the dried juice of the seed capsules of the white poppy. Laudanum is an alcoholic extract of opium. Morphine, which melts with decomposition at about 230°, is used as a narcotic. When distilled with zinc dust it yields phenanthrene, isoquinoline, pyridine, and pyrrole.

Heroin is a diacetyl derivative of morphine.

CHAPTER XXXI

URIC ACID AND RELATED COMPOUNDS

718. Uric acid was first isolated from urine in 1776 by Scheele. The acid and the compounds related to it have been investigated for many years by some of the great masters of organic chemistry. A complete account of these investigations forms one of the most interesting chapters of the science. The relationship which exists between the members of this group of compounds was finally established by the researches of Emil Fischer. Only the more important conclusions will be given here.

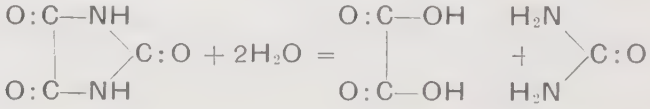
Uric acid, $C_5H_4N_4O_3$, occurs in small quantity in normal urine; a man excretes daily about 0.7 gram of the acid. In gout, uric acid is deposited in the joints and under the skin as a difficultly soluble acid salt. It also occurs in the form of urinary calculi in the bladder. The ammonium salt of uric acid is the chief constituent of the excrement of birds and reptiles. The acid is most conveniently prepared from guano or the excrement of snakes.

Uric acid is difficultly soluble in water; at 18.5° 1 part of acid dissolves in 10,000 parts of water. It is a weak dibasic acid, which forms two series of salts. The normal sodium salt has the composition $C_5H_2N_4O_3Na_2.H_2O$ and is soluble in 62 parts of water at room temperature. The acid salt, $2(C_5H_3N_4O_3Na).H_2O$, is soluble in about 1,100 parts of water at 15°. Normal lithium urate is moderately soluble in water; on account of this fact lithia water has been suggested as a remedy for gout.

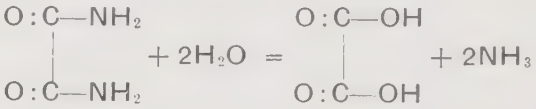
Conclusions as to the structure of uric acid have been arrived at from the study of the products formed as the result of the oxidation of the acid. Among the oxidation products are parabanic acid and alloxan, which are formed when uric acid is treated with nitric acid, and allantoin, which results from the oxidation of the acid with potassium permanganate. The

structure of these substances must be studied before an understanding of the configuration of uric acid can be reached.

719. Parabanic Acid, $C_3H_2N_2O_3$.—Under certain conditions an acid of this formula is obtained by oxidizing uric acid with nitric acid. The structure of parabanic acid is deduced from the decomposition which results when the acid is hydrolyzed by an alkali; urea and oxalic acid are formed:

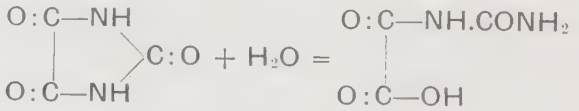


In this reaction parabanic acid resembles an amide; oxamide on hydrolysis yields oxalic acid and ammonia:

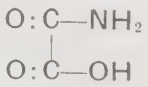


In parabanic acid, however, the two hydroxyl groups of oxalic acid are replaced by the residue of urea. Other dibasic acids form analogous compounds, which are called ureides. Parabanic acid is, thus, oxalyl ureide; it is also called oxalylurea.

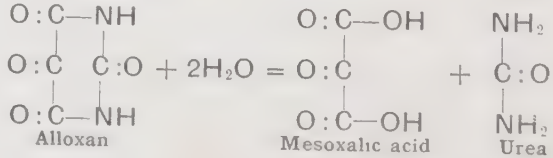
By careful hydrolysis, but one molecule of water is added to parabanic acid:



The acid formed is called oxaluric acid. It resembles oxamic acid in structure:

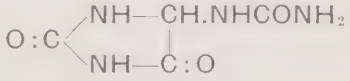


720. Alloxan, $C_4H_2N_2O_4$, is shown by its hydrolysis to be the ureide of mesoxalic acid:

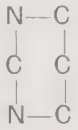


Alloxan crystallizes with three molecules of water, one of which is not removed when the acid is heated to 100°. (*Cf.* glyoxylic acid, **335.**)

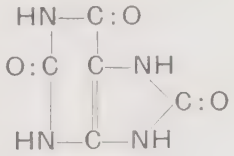
721. Allantoin, $C_4H_6N_4O_3$, (m.p. 235°) is formed when uric acid is oxidized by potassium permanganate. The products of hydrolysis of allantoin, and its synthesis from glyoxylic acid and urea, lead to the structure which is represented by the formula



722. Structure of Uric Acid.—The formation of allantoin from uric acid is evidence that the latter contains two urea residues; and the formation of alloxan, that it contains the arrangement of atoms represented by the symbols



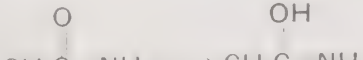
These facts lead to the view that the structure of uric acid is that represented by the formula



Uric acid

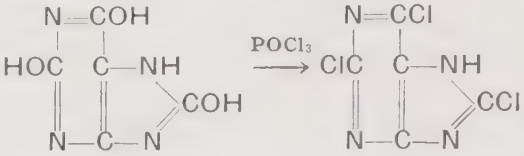
Many other facts, which cannot be discussed here, lead to the same conclusion. With this structural formula as a guide, uric acid has been synthesized in a number of ways.

It is probable that a number of substitution products of uric acid is derived from a tautomeric form of the acid. It will be recalled that there is evidence for the view that certain compounds related to amides are derived from a tautomeric form of these compounds:



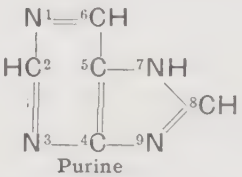
In some of its reactions urea behaves as if it had a structure similar to the tautomeric form of amides:

With certain reagents, for example phosphorus oxychloride, uric acid acts in a manner which indicates that it has the tautomeric configuration:



The product formed by this reaction is called trichloropurine.

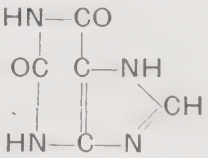
723. Purine (m.p. 217°) is obtained from trichloropurine by treatment with hydriodic acid, which converts it into diiodopurine, and subsequent reduction of the latter by zinc dust. Purine is of interest as it is the compound from which uric acid and xanthine may be considered as derived by substitution. For convenience of reference the atoms in purine are numbered in the following way:



Purine

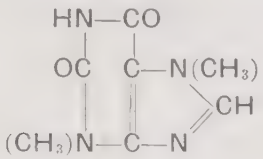
The compound formed by the action of phosphorus oxychloride on uric acid is, accordingly, 2,6,8-trichloropurine.

724. Xanthine, 2,6-dioxypurine,



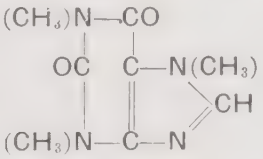
is present in the tissues of the body, and is an important constituent of certain proteins which occur in the body cells. The salts formed by xanthine with bases are decomposed by carbonic acid; those formed with acids are more stable, although the compound is only weakly basic.

725. Theobromine, 3,7-dimethyl-2,6-dioxypurine,



is a dimethyl substitution product of xanthine. It is prepared from cacao beans, and is present in chocolate to the extent of from 1 to 2 per cent. Theobromine is a white crystalline powder which is soluble with difficulty in water. It sublimes unchanged at about 290°. It forms with strong acids salts, which crystallize well and are hydrolyzed by water. It also acts as a weak acid. It can be prepared from xanthine by treating the lead salt of the latter with methyl iodide.

726. Caffeine or theine, 1,3,7-trimethyl-2,6-dioxypurine, is



a constituent of coffee and tea. Coffee beans contain about 1 per cent of caffeine. The compound crystallizes from water in needles, which contain one molecule of water of crystallization. Anhydrous caffeine melts at 237°. It dissolves in about 70 parts of water at 16° and in about 2 parts of 65°. Caffeine forms well-characterized salts with acids; the nitrate has the composition $C_8H_{10}N_4O_2.HNO_3$. Caffeine has been prepared from theobromine by introducing into the latter a third methyl group. The structures of caffeine and theobromine have been determined by a study of the products formed on their oxidation. Caffeine yields, when carefully oxidized, dimethylalloxan and methylurea.

CHAPTER XXXII

PROTEINS

727. Under the general term *protein* are classed many complex nitrogenous organic compounds which occur abundantly in plants and animals; white of egg, gelatin, and the hair of animals are typical proteins. The proteins are of the greatest importance as they are present in all living cells, are essential to life processes, and are a necessary constituent of animal foods. On account of their great complexity in composition our knowledge of the proteins is not as definite as that of many other compounds which occur in nature.

728. Physical Properties of Proteins.—Most proteins are colorless, amorphous substances. They have no definite melting points or boiling points, but carbonize on heating and give off gases. The proteins differ widely from one another as to solubility in water, in solutions of salt, and in dilute alcohol. They are all insoluble in pure organic solvents.

The soluble proteins are precipitated from aqueous solutions by a large number of salts. These salts may be divided into two classes, namely, those, such as sodium chloride and ammonium sulphate, which precipitate (salt out) the protein in an unchanged condition, and those which form insoluble compounds with the protein, such as the salts of copper and silver. "Salting out" is an important means of separating proteins from complex mixtures obtained from animal and plant tissues and from one another.

When alcohol is added to a solution of a protein, the latter is precipitated unchanged. If, however, the precipitate is allowed to stand in contact with strong alcohol for some time, a change takes place as the result of which the protein becomes insoluble in water. It is said to be coagulated. Coagulation is also produced by heat; this will be discussed later.

Proteins, like other colloidal substances, do not pass through semipermeable membranes, such as parchment and collodion, and consequently can be separated from adhering inorganic salts by dialysis.

The solutions of all proteins are optically active. Most proteins are amorphous substances. Some have been obtained, however, in crystalline condition. Edestin, a well-characterized protein which occurs in a number of seeds, can be crystallized from a warm 5 per cent solution of sodium chloride. Egg albumin, after precipitation from solution by ammonium sulphate and acetic acid, yields a crystalline protein on standing.

729. *Molecular Weights of Proteins.*—Investigations of the molecular weights of proteins indicate that the number of atoms in the molecules of these substances is very large. The application of the usual method of calculating molecular weights from the extent of the lowering of the freezing point of solutions yields in the case of proteins unreliable results because the effect is very small; and, further, uncertainty arises from the fact that it is very difficult, if not impossible, to free the protein from adhering inorganic substances.

The percentage composition of a substance can be used to calculate the lowest molecular weight that the substance can possess. For example, oxyhemoglobin, purified by crystallization, contains 0.34 per cent of iron. If there is present in the molecule but one iron atom, weighing 56, the molecular weight must be 16,500. The actual molecular weight is this value or some multiple of it.

The measurement of the osmotic pressure of solutions of highly purified proteins has yielded, in all probability, the most reliable values of the molecular weights of these compounds. The values recently assigned to a few proteins are as follows: ovalbumin 34,000; serum albumin 45,000; gelatin, 150,000; casein, 192,000.

730. Chemical Properties of the Proteins.—The proteins that occur in nature may be divided into two main classes, the simple proteins, which resemble one another closely in chemical composition, and the so-called conjugated proteins, which are compounds of simple proteins with other complicated organic complexes. The conjugated proteins are readily decomposed

into their constituents by mild chemical treatment, such as the action of cold hydrochloric acid.

Composition.—The simple proteins contain carbon, hydrogen, nitrogen, oxygen, and sulphur. The percentages of carbon and hydrogen vary within narrow limits—from approximately 50 to 55 per cent of the former and 6 to 7 per cent of the latter. Although the amount of sulphur in proteins is relatively small, the variations in the amount are great. For example, egg albumin contains 1.6 per cent of sulphur, the albumin of wheat 1.3, zein from maize 0.6, human nails 2.8, and human hair 5.0. The mixture of proteins obtained from animal sources contains approximately 16 per cent of nitrogen.

Phosphorus is also present in certain proteins in small proportion; casein contains about 0.9 per cent of this element. Iodine is a common constituent of the proteins of marine animals. Sponges yield a protein which contains 9 per cent of this halogen.

731. The Determination of the Percentage of Proteins in Natural Products.—The substance to be analyzed is oxidized by heating it with concentrated sulphuric acid (Kjeldahl method), usually in the presence of a catalytic agent such as mercuric sulphate. The nitrogen in the protein is set free as ammonia, which unites with the excess of sulphuric acid present. A strong solution of sodium hydroxide is next added and the solution is distilled. The ammonia is collected in a solution of standardized acid. By titrating the excess of the acid, the amount of ammonia and, therefore, of nitrogen can be calculated. Assuming that the protein in the mixture contained 16 per cent of nitrogen the weight of the former can be calculated by multiplying the weight of nitrogen obtained by 6.25 ($^{100}/_{16}$). This factor, 6.25, was formerly used in calculating the weight of protein in all analyses for proteins. The careful study of vegetable proteins has shown that they vary markedly in the percentage of nitrogen they contain. For example, the legumin of peas contains 18.04 per cent of nitrogen and the zein of maize only 16.13 per cent. It is evident that the factor 6.25 should not be used in calculating the amount of protein in samples of peas and corn. At present the factor used is determined by the particular protein present provided its content of nitrogen is known.

732. Coagulations of Proteins.—When aqueous solutions of certain proteins are heated, the protein separates and is said to be coagulated. The reaction is irreversible, *i.e.*, the coagulated protein cannot be brought into solution without subjecting it to the action of reagents which bring about decomposition. The coagulated proteins are obtained as amorphous substances, which

dry to a powder and are insoluble in water and solutions of salts. The temperature at which coagulation takes place varies with different proteins. This temperature is affected by the presence of neutral salts in solution, and by the amount of acid or alkali present. Under certain conditions, however, these temperatures are definite and their determination is often made use of in studying proteins.

733. Hydrolysis of Proteins.—The recent advances which have been made in the knowledge of the chemistry of proteins have been the result of the study of the products formed in the hydrolysis of these highly complicated compounds. The proteins are hydrolyzed when heated with concentrated hydrochloric acid or with strong (about 25 per cent) sulphuric acid. The hydrolysis is also effected by certain enzymes which occur in plants and animals. The products obtained from the simple proteins are amino acids, the separation of which is attended with considerable difficulty. The method devised by Emil Fischer has proved most generally applicable. It consists, in the main, in converting the acids into esters, and subjecting the latter to fractional distillation under diminished pressure. The method yields only roughly quantitative results, as by its use it is possible to obtain a knowledge of but about 70 per cent of the total products resulting from hydrolysis.

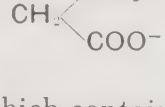
In a recent method introduced by Dakin the amino acids obtained as the result of hydrolysis by sulphuric acid are separated by means of solvents and by fractional crystallization; *n*-butyl alcohol has been shown to be an excellent substance for this purpose.

A large number of amino acids have been obtained from most proteins. The products may be divided into three classes according to the relationship between the number of carboxyl and of amino groups present in the acid. In one class are acids which contain *one* amino to *one* carboxyl group; glycine, aminoacetic acid, CH_2NH_2COOH, is an example. In another class are the acids which contain *one* amino to *two* carboxyl groups, such as aspartic acid, aminosuccinic acid, $HOOC.CH_2.CHNH_2.COOH$. The third class contains the acids having *two* amino groups to *one* carboxyl group. An example, in this case, is lysine, α, ϵ-diaminocaproic acid.

734. The Acidic and Basic Properties of Proteins.—The proteins which are soluble in water differ in their behavior with acids and bases. Some form salts with strong bases and others with strong acids. The majority of these proteins, however, are amphoteric and form salts with both acids and bases. Some proteins which are insoluble in water, dissolve in solutions of acids or of bases as the result of the formation of soluble salts. The protein can be recovered from these salts by treating the solutions, the latter with a base or an acid respectively. If strong solutions of the reagents are used, partial hydrolysis of the protein may take place.

The salts of proteins are ionized in solution. In salting out (**728**) a protein by adding an inorganic salt to the solution, it is necessary to avoid the presence of the protein salts in order to obtain complete precipitation. This is accomplished by having the solution at the *isoelectric point*, which is defined as the hydrogen-ion concentration at which the protein is in combination with neither acid nor base, and consequently contains the minimal quantity of colloidal ions.

The acidic and basic properties of a protein are related to the composition of the amino acids formed as the result of its hydrolysis. If the acids contain a larger number of amino groups than of carboxyl groups the protein will show basic properties; and the reverse is true. It has been stated (**355**) that the monoaminocarboxylic acids are probably inner salts formed as the result of the interaction of the amino and carboxyl groups present; in order to emphasize this view, the formula of glycine was written as follows:



Compounds of this class which contain one of each kind of group will be practically neutral; they will form salts, however, with strong bases and strong acids.

It will be shown later that the most probable way in which the amino acids are linked together in a protein molecule is that which would result from the interaction, with the loss of water, of the carboxyl group of one molecule and the amino group of another. For example, a compound formed in this way from α-amino-

propionic acid and aminoacetic acid has the structure shown in the following equation:

$$CH_3CH_2NH_2COOH + NH_2CH_2COOH = CH_3CH_2NH_2CO.NHCH_2COOH + H_2O$$

The resulting compound contains one amino and one carboxyl group and possesses the properties of compounds of this class.

If one of the acids involved in the union has one carboxyl and two amino groups the same relation will exist in the condensation product, which accordingly will be basic; if the acidic groups are in excess the product will be acidic.

It has been found as a result of the quantitative study of the amino acids formed from proteins by hydrolysis that the acidic or basic properties of the protein bear a direct relationship to the relative amounts of the various classes of acids obtained. For example, the acidic proteins from certain seeds, such as zein (from maize) and gliadin (from wheat) yield a high percentage of glutamic acid, which contains two carboxyl groups to one amino group, and no lysine, which contains two amino groups and one carboxyl group. Casein (from milk) has amphoteric properties; it will neutralize twice as many equivalents of a base as of an acid. The relation between the amounts of diamino-monocarboxylic acids and monoamino-dicarboxylic acids, formed as the result of hydrolysis, is in accord with this fact.

735. Amino Acids Obtained from Proteins.—In the table given below are listed the amino acids of known structure which have been isolated from the products obtained as the result of the hydrolysis of proteins. It should be noted that they all contain an amino group in the *alpha* position to a carboxyl group, except in the case of proline; and that in this case the basic NH of the pyrrolidine ring is in the position *alpha* to the acidic group.

AMINO ACIDS OBTAINED FROM PROTEINS

I. Acids Containing One Basic to One Acidic Group.

Glycine	$CH_2NH_2.COOH$ Aminoacetic acid
Alanine	$CH_3CHNH_2.COOH$ α-Aminopropionic acid
Serine	$CH_2OH.CHNH_2.COOH$ β-Hydroxy-α-aminopropionic acid

Phenylalanine..... $C_6H_5CH_2.CHNH_2.COOH$

β-Phenyl-α-aminopropionic acid

Tyrosine..... $HOC_6H_5.CH_2.CHNH_2.COOH$

β-Parahydroxyphenyl-α-aminopropionic acid

Cystine..... $SCH_2CHNH_2.COOH$ / $SCH_2CHNH_2.COOH$

β, β′-Dithiobis [α-aminopropionic] acid

α-Aminobutyric acid..... $CH_3.CH_2CHNH_2COOH$

α-Aminobutyric acid

Valine..... $(CH_3)_2CH.CHNH_2COOH$

α-Amino-isovaleric acid

Leucine..... $(CH_3)_2CH.CH_2.CHNH_2COOH$

α-Amino-isocaproic acid

Norleucine..... $CH_3.CH_2.CH_2.CH_2.CHNH_2.COOH$

α-Aminocaproic acid

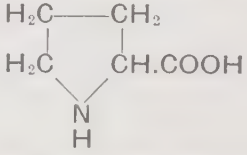
Isoleucine..... $CH_3.CH_2CH(CH_3).CHNH_2.COOH$

α-Amino-β-methyl-valeric acid

Thyroxine..... $HOC_6H_2I_2.O.C_6H_2I_2.CH_2.CHNH_2.COOH$

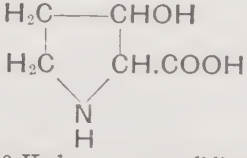
β-[4-Hydroxy-3,5-diiodo-4-(3,5-diodo-phenoxy) phenyl]-α-aminopropionic acid

Proline.....



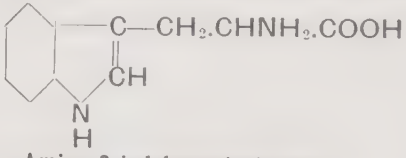
α-Pyrrolidinecarboxylic acid

Hydroxyproline.....



β-Hydroxy-α-pyrrolidinecarboxylic acid

Tryptophane.....



α-Amino-3-indolepropionic acid

II. Acids Containing Two Acidic Groups to One Basic Group.

Aspartic acid..... $HOOC.CH_2.CHNH_2.COOH$

Aminosuccinic acid

Glutamic acid..... $HOOC.CH_2.CH_2.CHNH_2.COOH$

α-Aminoglutaric acid

Hydroxyglutamic acid..... $HOOC.CH_2.CHOH.CHNH_2.COOH$

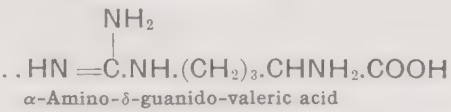
β-Hydroxy-α-aminoglutaric acid

III. Acids Containing More than One Basic Group to One Acid Group.

Lysine.....$CH_2NH_2.(CH_2)_3.CHNH_2.COOH$

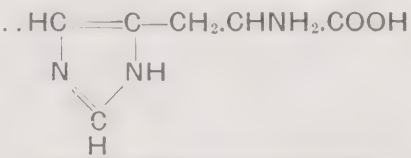
α,ϵ-Diaminocaproic acid

Arginine.....



α-Amino-δ-guanido-valeric acid

Histidine.....



α-Amino-5-imidazolepropionic acid

736. *Composition of Typical Proteins.*—Much work has been done on the determination of the relative amounts of the various acids formed on the hydrolysis of proteins. The methods of separating the complex mixture of acids into its constituents are but approximately quantitative, and it has been found impossible, up to the present, to isolate the acids in such a way that the amount obtained is equivalent to the weight of protein used. Important results have been obtained, however. While the simple proteins do not differ greatly in chemical composition and yield the same amino acids on hydrolysis, they are made up of these acids in widely different proportions. Proteins which belong to the same class often resemble one another closely in chemical composition. The vegetable proteins, such as gliadin and zein, yield a large proportion of glutamic acid on hydrolysis. The keratins, which are the chief constituents of hair, nails, horn, hoofs, etc., are characterized by the high percentage of cystine which they contain. Gelatin yields a high percentage of glycine, but no tyrosine, tryptophane, or cystine.

737. Classification of Proteins.—Although much light has been thrown on the chemical nature of the proteins as the result of the study of their hydrolysis it is still impossible to classify them on a strictly chemical basis. Much confusion has arisen in the nomenclature of the proteins as the result of the fact that different writers have assigned different meanings to certain terms which have been used in classifying these compounds. The nomenclature which is given below is that adopted by the American Society of Biological Chemists and the American Physiological Society.

I. Simple Proteins.—Protein substances which yield only α-amino acids or their derivatives on hydrolysis. The various groups of simple proteins are designated as follows:

a. Albumins.—Simple proteins soluble in pure water and coagulated by heat.

b. Globulins.—Simple proteins insoluble in pure water, but soluble in neutral solutions of salts of strong bases with strong acids.

c. Glutelins.—Simple proteins insoluble in all neutral solvents, but readily soluble in *very* dilute acids and alkalies.

d. Alcohol-soluble Proteins, Prolamins.—Simple proteins soluble in relatively strong alcohol (70 to 80 per cent), but insoluble in water, absolute alcohol, and other neutral solvents.

e. Albuminoids.—Simple proteins which possess essentially the same chemical structure as the other proteins, but are characterized by great insolubility in all neutral solvents.

f. Histones.—Soluble in water and insoluble in very dilute ammonia and in the absence of ammonium salts, insoluble even in an excess of ammonia; yield precipitates with solutions of other proteins and a coagulum on heating which is easily soluble in very dilute acids. On hydrolysis they yield a large number of amino acids, in which the basic ones predominate.

g. Protamines.—Simpler polypeptides than the proteins included in the preceding groups. They are soluble in water, uncoagulated by heat, have the property of precipitating aqueous solutions of other proteins, possess strong basic properties, and form stable salts with strong mineral acids. They yield comparatively few amino acids, among which the basic amino acids predominate.

II. Conjugated Proteins.—Substances which contain the protein molecule united to some other molecule or molecules otherwise than as a salt.

a. Nucleoproteins.—Compounds of one or more protein molecules with nucleic acid.

b. Glycoproteins.—Compounds of the protein molecule with a substance or substances containing a carbohydrate group other than a nucleic acid.

c. Phosphoproteins.—Compounds of the protein molecule with some, as yet undefined, phosphorus-containing substance other than a nucleic acid or lecithins.

d. Hemoglobins.—Compounds of the protein molecule with hematin or some similar substance.

e. Lecithoproteins.—Compounds of the protein molecule with lecithins (lecithans, phosphatides).

III. Derived Proteins.

1. *Primary Protein Derivatives.*—Derivatives of the protein molecule apparently formed through hydrolytic changes which involve only slight alterations of the protein molecule.

a. Proteans.—Insoluble products which apparently result from the incipient action of water, very dilute acids, or enzymes.

b. Metaproteins.—Products of the further action of acids and alkalies whereby the molecule is so far altered as to form products soluble in very

weak acids and alkalies, but insoluble in neutral fluids. This group includes what are ordinarily called acid albuminates and alkali albuminates, but does not include the salts of proteins with acids.

c. Coagulated Proteins.—Insoluble products which result from the action of heat on their solution, or the action of alcohols on the proteins.

2. *Secondary Protein Derivatives.*—Products of the further hydrolytic cleavage of the protein molecule.

a. Proteoses.—Soluble in water, uncoagulated by heat, and precipitated by saturating their solutions with ammonium sulphate or zinc sulphate.

b. Peptones.—Soluble in water, uncoagulated by heat, but not precipitated by saturating their solutions with ammonium sulphate.

c. Peptide.—Definitely characterized combinations of two or more amino acids, the carboxyl group of one being united with the amino group of the other with the elimination of a molecule of water.

738. Qualitative Reactions of Proteins.—All proteins are built up in the same general way from simple molecules, and show therefore similar reactions with a large number of reagents. No one of these reactions is characteristic for proteins, but if a substance gives several of them it may be safely considered as a member of this class. Some of these tests are briefly described below.

A. Precipitation Reactions.—Proteins may be precipitated from solutions by the following reagents:

I. *Various Mineral Acids.*—Nitric acid is often used. If the acid is allowed to flow under a protein solution a white ring forms at the junction of the acid and the solution. This reaction, which is known as *Heller's test*, is a very delicate one, and is used in detecting albumin in urine. Peptones are not precipitated by nitric acid.

II. *A Mixture of Potassium Ferrocyanide and Acetic Acid.*—The precipitation is produced as the result of the formation of ferrocyanic acid, which forms an insoluble compound with the protein. The reaction is used clinically as a test for albumin. Ferrocyanic acid gives but a faint precipitate with gelatin and does not precipitate peptones.

III. *The Ordinary Alkaloidal Reagents.*—The reagents which precipitate alkaloids from their solutions react also with proteins. Among these may be mentioned phosphotungstic acid, phosphomolybdic acid, tannic acid, picric acid, potassium mercuric iodide, and potassium bismuth iodide. The alkaloidal reagents precipitate the majority of the proteins in acid solution only. Tannic acid, phosphomolybdic acid, and phosphotungstic acid precipitate peptones. Most of the acid aniline dyes and many of the organic color bases also precipitate proteins.

IV. *The Salts of the Heavy Metals.*—Most proteins are precipitated by the salts of heavy metals as insoluble metallic compounds from acid, neutral, or alkaline solutions. Copper acetate, mercuric chloride, and lead acetate are commonly used for this purpose.

739. *B. Color Reactions.*—Some of the more important color reactions of the proteins are given below. All these reactions are not shown by every

protein, as the colors produced are due to the presence of certain spec groups, which may or may not be present in a particular protein. Ev protein will give, however, a positive reaction in a large number of the tes

I. *Biuret Reaction.*—When a protein is treated with a solution of sodi hydroxide, and a dilute solution of copper sulphate is added drop by dr a pink-violet to blue-violet color is produced. The peptones give a pi coloration in this test. The test is known as the biuret reaction as it shown by biuret (**228**).

II. *Xanthoproteic Reaction.*—When proteins are treated with strong nit acid a yellow coloration or yellow solid is formed. It is sometimes necessa to heat the solution to boiling to get a positive test. If an excess of amm nium hydroxide is added to the solution, the yellow substance formed by t acid is changed in color to orange. The production of the color in this te is probably associated with the presence of a benzene ring in the compoun When many simple derivatives of benzene are treated with strong nit acid, the nitro substitution products formed have a yellow color.

III. *Millon's Reaction.*—The reagent for this test is a solution of mercu in nitric acid containing nitrous acid. When the reagent is added to a sol tion or suspension of the protein in water, there is obtained either in t cold, or after boiling, a pink coloration of the fluid, or a pink to brownish-r coloration of the precipitated protein. The reaction is given by all deriv tives of benzene in which one of the hydrogen atoms has been replaced by hydroxyl group. It thus serves as a delicate test for the presence of tyrosi in a protein.

IV. *Molisch Reaction.*—The test is the same as that applied to carb hydrates (**408**), and when positive in the case of a protein shows the presen in the latter of a carbohydrate. The test is applied by adding concentrate sulphuric acid to a solution of a protein containing a few drops of an alc holic solution of α-naphthol. A violet color is produced, which tur yellow on the addition of alcohol, ether, or sodium hydroxide. If thymol used instead of α-naphthol, a carmine-red color is produced, which chang to green on the addition of water.

V. *Sulphur Reaction.*—When a protein solution is warmed with a solutio which contains sodium hydroxide and a lead salt, either a black precipitat or brown coloration is produced. The reaction depends on the splitting o of sulphur from cystine, and the subsequent formation of lead sulphide.

VI. *Color Reactions Due to the Presence of the Tryptophane or Indole Deriv tives.—a.* The reaction of Adamkiewicz is carried out by treating a protei solution with one volume of concentrated sulphuric acid and two volume of glacial acetic acid. A reddish-violet color is produced.

b. Hopkins and Cole have shown that the color produced results from reaction between the protein and glyoxylic acid, which is present in glacia acetic acid. Glyoxylic acid is formed when glacial acetic acid is expose to oxygen in the sunlight. The test for protein is made by treating th latter with a solution of glyoxylic acid, which can be conveniently prepare by reducing oxalic acid with sodium amalgam.

740. Albumins.—Albumins have been isolated from blood serum, milk, and certain seeds. Albumins are soluble in pure water and form solutions which are neutral and are coagulated by heat. They are not precipitated when their solutions are saturated with sodium chloride or magnesium sulphate.

Serum albumins occur in the lymph and blood serum of vertebrates. *Lact-albumin* is found in all kinds of milk, but is present in relatively small amounts. Cow's milk contains from 0.35 to 0.50 per cent of albumin. *Egg albumin* forms the chief constituent of white of egg, which also contains a globulin and a mucoid (a glycoprotein). Among the vegetable albumins are *leucosin*, which is found in the seeds of wheat, rye, and barley; and *legumelin* which has been isolated from peas, lentils, and soy beans.

741. Globulins.—The globulins are simple proteins which differ from albumins in being insoluble in water and in dilute acids; they dissolve, however, in dilute alkalies and in solutions of neutral salts. Globulins have been isolated from blood serum, certain organs, the crystalline lens, eggs, milk, seeds, and other sources. *Fibrinogen*, which shows the general characteristics of the globulins, occurs in the blood plasma of all vertebrates. The fluid portion of the blood before coagulation takes place, is called plasma. As soon as blood leaves the body, the so-called fibrin enzyme converts the fibrinogen into *fibrin*, the change bringing about the clotting of the blood. The solution obtained after the removal of fibrin is called serum. Blood plasma contains about 0.4 per cent of this protein.

Sarcoplasma, the fluid contents of the sarcolemma sheaths of striped muscle, contains proteins from which have been isolated *myosin* (also called *musculin* or *paramyosinogen*) and *myogen* (or *myosinogen*). The coagulation of myosin which takes place after death gives rise to what is known as *rigor mortis*. Myogen constitutes about 80 per cent of the muscle protein. It is fairly soluble in water, has a neutral reaction, and is readily converted into a metaprotein by acids.

742. Glutelins and Prolamins.—Cereals contain, in addition to albumins and globulins, glutelins and the so-called alcohol-soluble proteins (*prolamins*). *Gluten*, the adhesive glue-like material present in wheat, which gives to dough its toughness, is considered to be a mixture of two proteins. One, called *glu-*

tenin, is a glutelin, which is insoluble in alcohol, water, or sa solutions; the other, called *gliadin*, is soluble in a mixture of wat and alcohol.

743. Albuminoids.—The proteins which are characterize by great insolubility in neutral solvents are classed as albu minoids. To this group belong the proteins which constitut the framework of the animal tissues and those which are impor tant constituents of the animal skeleton or cutaneous structure

Collagen constitutes the fibrils of connective tissue and th foundation of bone and cartilage. When collagen is treate with tannic acid it shrinks greatly and hardens, and a substance i formed which does not putrefy; the use of tannin in the prepara tion of leather is based upon these facts. When collagen i boiled with water it is converted by partial hydrolysis into *gelati* which passes into solution; on cooling, the gelatin solidifies t a jelly, which redissolves on heating. When gelatin is boile with water or with dilute solutions of acids or alkalies, th hydrolysis proceeds further; gelatoses, which do not possess th property of gelatinizing, are formed. The final products o hydrolysis are amino acids. This change is also brought abou by peptic and tryptic digestion. Gelatin (usually in impur form) is used as an adhesive under the name of *glue*.

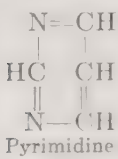
The *keratins* are the chief constituents of the epidermis an the horny substance found in mammals and birds; they occu in hair, hoofs, horns, wool, and feathers, and are the most insol uble of all the albuminoids. The keratins contain a relatively high percentage of cystine; human hair yields about 14 per cen of this acid. With nitric acid the keratins give a marked xantho proteic reaction which is observed, for example, when the acid comes in contact with the skin.

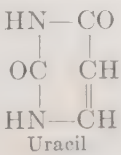
Elastin constitutes the yellow elastic fibers in ligaments and the outer wall of arteries. It is not affected by dilute acids o alkalies in the cold, but is digested by pepsin and hydrochloric acid. It yields 25 per cent of glycine and 21 per cent of leucine on hydrolysis. *Fibroin*, which is the chief constituent of the fibers of silk, differs markedly from the other albuminoids and albumins in composition. It contains about 19 per cent of nitrogen and yields on hydrolysis 36 per cent of glycine, 21 per cent alanine, and 10 per cent tyrosine.

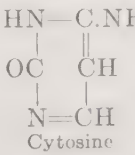
744. Histones are characterized by their basic character; they yield a high percentage of arginine and lysine on hydrolysis. They are soluble in water, and are precipitated on the addition of ammonia. The protein constituent of hemoglobin, the red coloring matter of the blood, is classed as a histone; it is called *globin*.

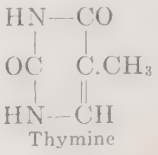
745. Nucleoproteins are composed of simple proteins, generally protamines, histones, or albumins, and a nucleic acid. They are the chief constituents of the cell nuclei, and in those organs especially rich in cells, such as the thymus and the lymph glands, exceed in quantity all other proteins. Nucleoproteins have been isolated from the spermatozoa of fish, the thymus, the pancreas, the thyroid, the liver, muscle, yeast, bacteria, and from certain plants. It is probable that the nucleoproteins play an important part in the building up of the cell plasm from the products formed as the result of the hydrolysis of the protein constituents of foods.

746. Nucleic Acids.—The nucleic acids obtained from nucleoproteins are of unknown constitution, but their dissociation products are fairly well known. They yield on hydrolysis phosphoric acid, pentoses, and derivatives of pyrimidine and of purine (**723**). It is beyond the scope of this book to discuss adequately the structure of the derivatives of pyrimidine and purine which are obtained from the nucleic acids. The graphic formulas of the derivatives which have been isolated are given here for reference. Uracil, cytosine, and thymine are derivatives of pyrimidine:

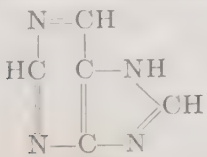

Pyrimidine

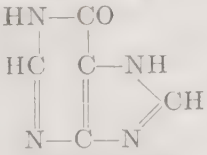

Uracil

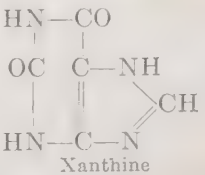

Cytosine

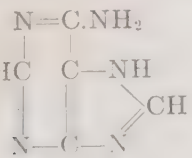

Thymine

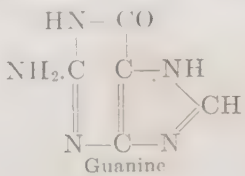
Hypoxanthine, xanthine, adenine, and guanine are derivatives of purine:


Purine


Hypoxanthine


Xanthine


Adenine


Guanine

It has been shown that in certain nucleic acids the phosphoric acid is joined to the pentose molecule, which in turn is linked to the pyrimidine or purine derivative.

747. Glycoproteins are characterized by yielding on hydrolysis a carbohydrate or a derivative of a carbohydrate, such as glucosamine. To this group belong the mucins, mucoids, and, a protein from white of egg. The glycoproteins, as a class, are difficultly soluble in water, are acids, and are uncoagulated by heat. *Mucins* form more or less adhesive solutions and are found in most of the slimy fluids occurring in the body. The *mucoids* differ from the mucins in not being precipitated by acids. They are found in blood serum, in the white of egg, and along with collagen in the tissues.

748. Phosphoproteins.—Proteins of this class, when subjected to the action of pepsin and hydrochloric acid, undergo hydrolysis, and yield proteoses and an acid containing phosphorus, which is called paranucleic acid. This acid is sharply distinguished from the nucleic acids, as neither xanthine bases, pyrimidine derivatives, nor pentoses occur among its dissociation products. Paranucleic acid has not been obtained in the pure condition, and its decomposition products are not definitely known. The phosphoproteins are distinctly acid, are insoluble in water, and form soluble salts which contain the alkali metals and ammonium.

Casein, which is a phosphoprotein, is the chief nitrogenous constituent of milk, in which it occurs as a calcium salt in combination with calcium phosphate. Casein is insoluble in water, but its salts are readily soluble; those of calcium, barium, strontium, and magnesium form opalescent colloidal solutions. The sodium, potassium, and ammonium salts form comparatively clear solutions, which pass through clay filters. Casein also forms salts with acids. It is precipitated from a solution of its salts and from milk by small quantities of mineral acids, and by larger amounts of acetic acid, but it dissolves in an excess of acid. Casein and its salts are precipitated from solutions by saturating the latter with sodium chloride, magnesium sulphate, or sodium sulphate. The solutions of the salts of casein may be boiled without undergoing coagulation.

The casein in milk is coagulated in the presence of calcium salts by rennin, an enzyme found in rennet, which is made from the mucous membrane of the stomach of the calf. The product formed is called *paracasein;*[1] it resembles casein in being soluble in alkalies, but its calcium salt is insoluble. The coagulation produced by rennin results, therefore, in the conversion of the soluble calcium salt of casein into the insoluble calcium salt of paracasein. The caseins obtained from various sources resemble one another closely. That obtained from human milk, however, gives a pronounced carbohydrate reaction when tested with the Molisch reagent, while the casein from cow's milk gives but a very faint reaction.

Vitellin is a protein which contains phosphorus and yields a paranucleic acid on hydrolysis. It has been obtained from the yolk of hen's eggs. Its coagulation temperature is given as 75°.

749. Hemoglobins.—The conjugated proteins of this class occur in the red coloring matter of the blood of vertebrates and invertebrates. The red corpuscles of mammals are composed largely of hemoglobin. The dried red blood corpuscles in man contain 94.3 per cent and those in the dog 86.5 per cent of this protein. Hemoglobin is composed of a basic protein, called *globin*, which resembles the histones in character, and *hematin*, a substance which contains iron and is not a protein. It is probable that hemoglobins from different sources differ in composition, but the essential constituent which contains iron is the same in all. Hemoglobin combines directly with oxygen, carbon monoxide, and other compounds and forms substances which readily undergo dissociation into their components. This power of hemoglobin to form a loose compound with oxygen is of vital importance in animal physiology. Hemoglobin is the carrier of oxygen to all the tissues. Oxyhemoglobin can be obtained readily in a crystalline form.

When treated with acids or alkalies, hemoglobin is converted into globin and hematin. Hematin is obtained as a non-crystalline bluish-black powder, which is insoluble in water but

[1] There is confusion in the naming of the proteins which are called here by the names usually given to them, *viz.*, casein and paracasein. Some authors designate these substances by the more logical names caseinogen and casein, respectively.

soluble in alkaline solutions. Hydrochloric acid converts hematin into hemin, a substance which crystallizes in characteristic microscopic chocolate-colored plates. This reaction forms the basis of a very delicate method of detecting bloodstains. The composition of hemin, $C_{34}H_{32}ClFeN_4O_4$, has been established by Hans Fischer, who synthesized the compound in a way that added much to the knowledge of its structure. Hemin is a derivative of pyrrole.

750. Derived Proteins.—The metaproteins are obtained by treating proteins with dilute acids or alkalies. The derived proteins resemble closely the substances from which they are formed except in solubility. The nature of the change is not understood. It is possible that the conversion of a protein into a primary derivative may be associated with a change in the colloidal condition of the molecule.

The secondary protein derivatives result from hydrolytic cleavage. As proteins yield a large number of amino acids on complete hydrolysis, it is evident that they are built up by the combination of these acids as the result of the elimination of water. When a molecule so constituted is cautiously hydrolyzed, it is conceivable that hydrolysis may take place in stages, *i.e.*, it may yield 2, 3, 4, etc., parts which, on further hydrolysis, may break into simpler molecules. The final stage is that which yields the simple amino acids. An examination of the products formed as the result of the partial hydrolysis of proteins leads to accepting this view as correct. The products of hydrolysis are mixtures, and the classification adopted for them is, therefore, arbitrary. As hydrolysis of a protein proceeds, the substances first obtained are soluble in water, not coagulable by heat, and are precipitated by saturating their solutions with ammonium sulphate. These are called *proteoses*. Albumins yield albumoses, globulins yield globuloses, etc. Continued hydrolysis results in a further cleavage of the molecule, and the resulting products, called *peptones*, are not precipitated by ammonium sulphate. During the entire process of hydrolysis amino acids are formed along with the proteoses and peptones. The peptones on further hydrolysis are converted into peptides, and finally into amino acids.

Peptides are compounds formed as the result of the condensation of two or more molecules of amino acids, with the elimination of water. The structure of a number of peptides obtained by the hydrolysis of proteins has been established as the result of their synthesis from acids of known constitution. It is probable that the simple proteins and their more complex cleavage products are polypeptides, or mixtures of polypeptides, which are compounds formed as the result of the condensation of a number of amino acids. The term peptide in the system of nomenclature which has been given (**737**) is reserved for definitely characterized compounds of this type.

Hydrolysis of proteins is effected by acids, bases, and certain enzymes. The extent to which the cleavage takes place is determined, in the case of acids, by their concentration, the temperature, and the length of time during which the action is allowed to take place. In the case of enzymes, the results are determined by the nature of the enzyme. *Pepsin*, which is present in the gastric juice, and *trypsin*, the enzyme of the pancreatic fluid, have been much studied. Pepsin in the presence of hydrochloric acid converts proteins into peptones; trypsin brings about hydrolysis to amino acids.

751. Structure of Proteins.—Much light has been thrown on this problem as the result of the work of Emil Fischer on the peptides. A number of hypotheses have been put forward as to the way in which the amino acids obtained from proteins are linked to one another in the molecule. It is possible that the linking may be brought about through the direct union of carbon atoms, but this view seems improbable in the light of the fact that proteins are readily decomposed by hydrolysis. The amino acids obtained from proteins contain few hydroxyl groups other than those in the carboxyl group. This fact excludes the possibility that the linking is effected to any great extent through oxygen atoms. From the structure of the peptides, some of which have been obtained from natural sources, it is evident that nitrogen is the element that serves, in large measure, to hold together the parts of which the molecule is composed. The manner in which combination is effected is that shown in the

following equation, which illustrates the union of two molecules of glycine:

$$NH_2.CH_2.\overset{\overset{O}{\|}}{C}\!-\!OH + H\!NH.CH_2.COOH$$

$$= NH_2.CH_2.\overset{\overset{O}{\|}}{C}\!-\!NH.CH_2.COOH + H_2O$$

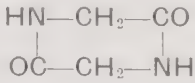
The nature of the union is similar to that in an amide:

$$CH_3CO\,OH + H\,NH_2 = CH_3CO.NH_2 + H_2O$$

The product formed as the result of the condensation of two molecules of glycine is called glycyl-glycine. According to the structure assigned to it, it is a substitution product of the amide of aminoacetic acid, $NH_2CH_2CO.NH_2$, in which one hydrogen atom is replaced by the group $CH_2.COOH$. Many facts are in accord with this view of the amide-like nature of the linking of amino acids in proteins. The proteins are hydrolyzed under the conditions used to effect the hydrolysis of amides. When proteins are treated with nitrous acid only a small amount of nitrogen is set free, a fact which shows that the protein molecule contains but a small proportion of its nitrogen as amino groups. It will be recalled that when a substance which contains this group, such as CH_3NH_2, is treated with nitrous acid the nitrogen present is set free, and the amino group is replaced by hydroxyl. The fact that proteins give the biuret reaction is further evidence that the molecules of amino acids of which they are built up are joined together in the way indicated. A study of the structure of the substances which give this reaction has shown that such compounds contain two CO—NH, two CS—NH, or two C(NH)—NH complexes, combined directly or by a carbon or nitrogen atom. Such a method of linking as that indicated above in the case of glycine, takes place in the living body. It has been shown that if benzoic acid, $C_6H_5.COOH$, and glycine, NH_2CH_2COOH, are taken into the system, they are excreted as hippuric acid, $C_6H_5CO.NH.CH_2COOH$. The acids found in the bile are compounds of this nature.

Recent work by Abderhalden and others indicates that the units in the protein molecule may consist of rings formed from

dipeptides as the result of the loss of water. Dipeptides, according to this view, would be derivatives of 3,6-diketopiperazine.



752. Synthesis of Polypeptides.—A number of methods have been devised to effect the union of amino acids in the manner which has been described, and to prepare compounds which have the structure resulting from such union. It is beyond the scope of this book to describe these methods in detail; only one of the more important methods used by Fischer will be mentioned briefly.

A synthetic method which has been very fruitful is based on the use of the chlorides of halogen-substituted acids. Chloroacetyl chloride and α-aminopropionic acid, for example, yield an acid, which is converted by ammonia into a dipeptide. The equation for the first reaction is as follows:

$$ClCH_2CO.Cl + NH_2CH(CH_3).COOH = ClCH_2CO.NHCH(CH_3).COOH + HCl$$

By the action of ammonia the chlorine atom is replaced by the amino group and glycyl-alanine is formed. By condensing α-bromopropionyl chloride with glycine, and subsequent treatment with ammonia, alanyl-glycine is formed:

$$CH_3.CHBr.COCl + NH_2CH_2.COOH \longrightarrow CH_3.CHBr.CO.NHCH_2.COOH \longrightarrow CH_3.CH(NH_2).CO.NHCH_2.COOH$$

It is thus possible by this method of synthesis to prepare peptides in which the acid radicals are joined in any desired order. Glycyl-alanine and alanyl-glycine are both made up of glycine and alanine, but in the former compound the carboxyl group is in the alanine residue, while in the latter it is in the glycine residue. Fischer prepared an octadecapeptide, which consists of 18 molecules of amino acids in combination. Its name is indicative of its structure: leucyl-triglycyl-leucyl-triglycyl-leucyl-octaglycyl-glycine. This substance had, at the time of its preparation, the highest molecular weight of any compound of known structure, which had been prepared by synthesis. Its molecular weight is 1,213.

753. Properties of Peptides.—The majority of peptides are readily soluble in water and insoluble in alcohol. Those which dissolve with difficulty in water are soluble in acids and in alkalies. Most of the peptides have a bitter taste and melt above 200° with decomposition. The simpler compounds give no precipitate with phosphotungstic acid, but many tripeptides and most tetrapeptides are precipitated by this reagent. Those which contain eight molecules of amino acids resemble in solubility the proteins. They are precipitated by phosphotungstic acid and tannic acid and are salted out by ammonium sulphate. Many tripeptides give the biuret reaction. The color produced when this test is applied to the peptides increases in intensity with increase in complexity of the molecule.

754. The behavior of the peptides when submitted to the action of hydrolytic agents is markedly similar to that of the proteins. The peptides are completely hydrolyzed to amino acids when heated with concentrated hydrochloric acid for 5 hours. The action of enzymes on the peptides furnishes a striking proof that some of them resemble the proteins in the manner in which the acids present are held in combination. Pepsin does not effect the hydrolysis of peptides. This fact is explicable, when we remember that this enzyme breaks down proteins into proteoses, peptones, and polypeptides only, and does not yield amino acids. It is highly probable that the peptones are polypeptides. It is possible that there are other methods of linking in proteins, and that these are broken by pepsin.

Certain peptides are hydrolyzed by trypsin, and certain ones are not. As trypsin converts proteins into amino acids, it is evident that the linking present in the peptides which are unaffected by trypsin is in all probability not involved in the building up of proteins. A study of the hydrolysis of peptides by trypsin and other hydrolytic enzymes has thrown much light on the structure of proteins. The subject is being actively investigated. Glycyl-alanine is not hydrolyzed by trypsin, whereas alanyl-glycine is hydrolyzed. If tyrosine or cystine is situated at the end of a chain in a peptide, they are split off by trypsin. If, on the other hand, they play the part of the acid radical, the molecule is not split at the union between the radical and the amino acid with which it is in combination. It is evident that such facts as these

are of the greatest value in the interpretation of the structure of the protein molecule.

Most of the acids obtained from proteins by hydrolysis with acids are optically active; alkaline hydrolysis yields racemic forms. Fischer prepared many optically active peptides and has discovered that the configuration of the molecule is an important factor in its hydrolysis by trypsin. For example, *d*-alanyl-*d*-alanine is hydrolyzed, but *d*-alanyl-*l*-alanine is not. Racemic peptides, *i.e.*, those which consist of a mixture of equal parts of dextro and levo compounds, are hydrolyzed asymmetrically, only one form, and that the form which occurs in proteins, being attacked by the enzyme. Up to the present, only those peptides have been hydrolyzed which contain the optically active forms of the amino acids which result from the hydrolysis of naturally occurring compounds.

By the careful hydrolysis of certain proteins, peptides of definite structure have been obtained. From silk fibroin have been obtained the anhydrides of glycyl-*d*-alanine and glycyl-*l*-tyrosine, and a tetrapeptide which consists of two molecules of glycine, one molecule of alanine, and one molecule of tyrosine. It has been shown that the products of the partial hydrolysis of elastin contain *d*-alanyl-*l*-leucine, alanyl-proline anhydride, and glycyl-valine anhydride. Other peptides have been obtained from gliadin and casein.

755. The Digestion and Metabolism of Proteins.—The digestion of proteins in the animal body is a process of hydrolysis which leads to the formation of the simpler derived proteins and amino acids. The change is brought about through the influence of enzymes which are present in the juices formed in the digestive tract. Gastric glands in the mucous lining of the stomach secrete a substance known as *pepsinogen*, which is converted into *pepsin* when it comes in contact with the hydrochloric acid formed in the gastric juice. The latter has an acidity equal to that of a 0.2 to 0.3 per cent solution of hydrochloric acid. Under the influence of the acid the pepsin causes the hydrolysis of proteins in the stomach largely to proteoses and peptones. The gastric juice also contains gastric *rennin* which causes the coagulation of casein.

The partly digested material passes next into the small intestine where the process of digestion is carried on by the substances present in the intestinal juice and the pancreatic juice. The latter contains *amylopsin* and *trypsinogen*. When the latter comes into contact with the enzyme *enterokinase* of the intestinal juice, *trypsin* is formed. This enzyme, in the presence of the

alkali in the intestinal juice, causes the hydrolysis of all forms of proteins. Unlike pepsin it causes the hydrolysis to proceed essentially to the complete splitting of the molecule to amino acids. The juice secreted by the small intestine contains the proteolytic enzyme *erepsin*, which, with a few exceptions, induces the hydrolysis of only the derived proteins to amino acids.

During the process of digestion amino acids are absorbed through the intestinal walls and are, in part, resynthesized into serum albumin which is carried by the blood to the muscle cells of the body where it is converted into body protein. A part of the protein furnished by the bloodstream is oxidized and furnishes energy. The products of this change are carbon dioxide, water, and nitrogen compounds such as urea, uric acid, and purine bases. The latter are excreted in the urine. If the food contains a deficit of fats and carbohydrates and an excess of protein, the latter is, in part, converted into carbohydrate, which furnishes the constant supply of glucose found in the blood. Either directly, or through a carbohydrate, proteins are also changed to fats.

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